NASA CR 152,101

(B. Lockhart)

DEVELOPMENT AND FABRICATION OF AN ADVANCED LIQUID COOLING GARMENT

By C. W. Hixon

6 March 1978

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PREPARED UNDER CONTRACT No. NAS2-9026 by
VOUGHT CORPORATION
Dallas, Texas

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

(NASA-CR-152101) DEVELOPMENT AND FABRICATION OF AN ADVANCED LIQUID COOLING GARMENT Final Report (Vought Corp., Dallas, Tex.) 87 p HC A05/MF A01 CSCL 06G

N81-16741

Unclas

G3/54 14469

DEVELOPMENT AND FABRICATION OF AN ADVANCED LIQUID COOLING GARMENT

Contract No. NAS2-9026
Report No. 2-53200/8R-3462

FINAL REPORT

6 MARCH 1978

Submitted by:

VOUGHT CORPORATION
DALLAS, TEXAS

To

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Ames Research Center
Moffet Field, California

Prepared by:

C. W. Hixon

Reviewed by:

J. A. Oren

Approved by:

R. L. Cox,
Project Engineer
Advanced Thermal Systems

D. C. Utterback,
Manager - Propulsion

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1.0 SUMMARY

This document is the final report on the tasks performed under contract (NAS2-9026 Modification 3) to the National Aeronautics and Space Administration - Ames Research Center (NASA-ARC). In accordance with the contract, a tube/fin concept liquid cooling garment (LCG) head cooler was developed, fabricated and delivered to NASA-ARC. The head cooler was fabricated from polyurethane film which sandwiches the transport fluid tubing and a thermally conductive fin material. The head cooler garment is sewn to form a skull cap and covered with a comfort liner. In addition, two Neonate heating garments were fabricated and supplied to NASA for further finishing and use in medical tests.

The resulting garment is flexible, elastic and conforms to the head comfortably. Tests on a tube/fin element of identical construction as the head cooler demonstrated good thermal effectiveness. Use of commercially available materials and development of relatively simple fabrication techniques give the potential for a low garment cost.

2.0 INTRODUCTION

Program tasks under Modification 3 to the Advanced Liquid Cooling Garment (LCG) contract involve five specific areas outlined as follows:

1. Advanced Materials Summary
2. Tube/Fin Layup Thermal Analysis
3. Head Cooler Fabrication
4. Thermal Comparison Testing
5. Production Cost Analysis of Tube/Fin Garments

In the materials survey, a combination of layup components was identified for use in the fabrication task. Refinements to the previous work on layup thermal analysis were made. Three LCG concepts (Flexitherm, Shuttle, and Tube/Fin) were evaluated by a thermal comparison test. To determine tube/fin garment costs, an analysis was performed to identify the fabrication steps and associated labor requirements in hours. These were combined with material costs to arrive at a garment cost.

Appendices are included which provide detail data on the fabrication development, production cost analyses, and the thermal comparison test.

3.0 TASK RESULTS

3.1 Advanced Materials Survey

Previous work investigated a number of materials suitable for tube/fin LCG fabrication. Under the present task, attention was narrowed to the most promising materials which are listed in Table 1. B. F. Goodrich makes both the TF322 and TF410 with the difference being TF322 is a polyester-based polyurethane and TF410 is a polyether-based polyurethane. The TF410 is more elastic than the TF322 for the same film thickness. TF410 film in the 1-1/2 mil thickness was selected for the head cooler although it is not always in stock due to light demand for this thickness. Special runs of a particular film thickness are always possible if the schedule demands, but are more expensive due to special set-up charges. Latex sheeting with Viton L-31 adhesive dipersion was attempted in a layup but the bond between layup components was extremely poor. Other adhesives were not pursued due to scope restrictions; however, if Latex were to be evaluated in the future it is recommended that additional adhesives be evaluated.

Both Nordbak adhesive resin systems were acceptable from a bonding strength standpoint but the 50-93 resin system was selected for its superior elasticity in the cured state. The 50-93 resin system is black when mixed and gives the layup the grayish color.

The metal mesh is listed for reference and no promising elastic thermal conductor candidates were idertified in addition to those in prior work. It was supplied by Exmet Corporation.

3.2 Tube/Fin Layup Thermal Analysis

Fin effectiveness models for the garment layup with two layers of expanded metal mesh are shown in Figure 1. One method assumes the open metal mesh is an equivalent solid metal film of reduced thickness. A second method analyzes the fin with independent metal strands of increased length due to open mesh zig-zag characteristic and is the more accurate of the two. Both methods neglect metal conduction parallel to the tubing (i.e., one dimensional fin conduction). Polyurethane film

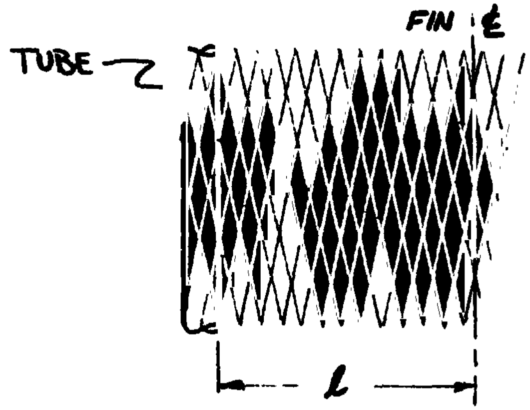
TABLE 1

MATERIALS SURVEY RESULTS

MATERIAL	COMMENTS
POLYURETHANE FILM TF322, TF410	TF410 HAS BETTER ELASTICITY BUT AVAILABILITY IN 1-1/2 MIL THICKNESS NOT ALWAYS GOOD. SPECIAL RUNS
LATEX SHEETING	SUITABLE ADHESIVE NOT IDENTIFIED FOR LATEX. VITON L-31 TRIED UNSUCCESSFULLY.
POLYURETHANE ADHESIVE NORDBAK 25-98 RESIN SYSTEM NORDBAK 50-93 RESIN SYSTEM	BOTH ACCEPTABLE BUT 50-93 SYSTEM MORE ELASTIC IN CURED STATE
COMFORT LINER LYCRA (STRETCH AND SEW) COTTON (T-SHIRT)	LYCRA HAS BETTER ELASTICITY THAN THE COTTON. LYCRA COST ($10/YD^2) 2.5 TIMES THE COTTON T-SHIRT
METAL MESH 3-Ag 5-2/0 FLATTENED	ELASTICITY POSSIBLE ACROSS THE SHORT DIMENSION OF THE DIAMOND PATTERN.

FIGURE 1 FIN EFFECTIVENESS MODELS

EQUIVALENT METAL THICKNESS



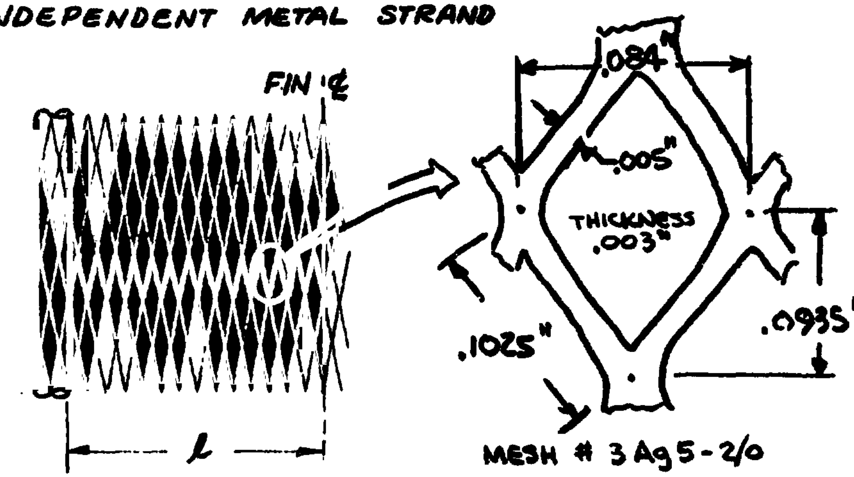
$\ell = \frac{1}{2}$ (TUBE SPACING - TUBE O.D.)

$$m = \sqrt{\frac{h}{kt}}$$

$$\eta = \frac{\tanh m\ell}{m\ell}$$

t = metal thickness if redistributed to form an equivalent continuous sheet

INDEPENDENT METAL STRAND



$\ell = \frac{1}{2}$ (TUBE SPACING - TUBE O.D.)

$\ell' = 2.44\ell$ (LENGTH OF METAL STRAND)

$$m = \sqrt{\frac{hP}{kA}}$$

h - fin contact heat xfer coeff.
P - contact perimeter for one metal strand & associated plastic film
k - metal conductivity
A - metal strand cross-section

$$\eta = \frac{\tanh m\ell'}{m\ell'}$$

conductance is also neglected since the film conductivity is 0.05% of that of the metal conductivity. All heat transfer is assumed to be from the contact interface with the warm surface.

Figure 2 shows the results of calculations using the two different fin effectiveness models discussed above. This graph also shows the effect of one and two layers of expanded silver mesh on fin effectiveness and presents the performance of the polyurethane film/glue composite, alone, for reference. All the garments made have two layers of silver mesh in the layup.

The polyurethane tubing represents a significant resistance to the layup heat transfer and Figure 3 is included showing two sizes of tubing and the effect of tube wall thickness on delta temperature. The test data range of heat transfer for the tube/fin test article is overlayed on the graph and shows predicted tube wall ΔT's in the $10^{\circ}F - 20^{\circ}F$ range. Since the heat transfer from the fluid through the tube wall is proportional to the temperature difference between the fluid and the surface being cooled, high flowrates and low inlet temperatures give the largest heat transfer per unit tube length and the largest ΔT.

From Figures 2 and 3 it is seen that thermal performance will be improved by spacing tubes closer, which increases fin effectiveness and reduces tube wall ΔT (by reducing $\dot{Q}/L$ per tube). The best spacing is a compromise between performance and practical factors, such as flexibility. A spacing of about 1 inch was selected for the metal mesh tube/fin LCG.

3.3 Head Cooler Fabrication

Nine patterned head garments, two Neonate garments, and a test article were fabricated as detailed in Table 2. Figure 4 lists the main steps. The Figure 5 garment flat pattern shows the approximate routing of the transport fluid tubing and the areas where metal mesh is used. Arrows on this chart indicate the direction of greatest elasticity of the metal mesh. Figure 6 shows the layup.

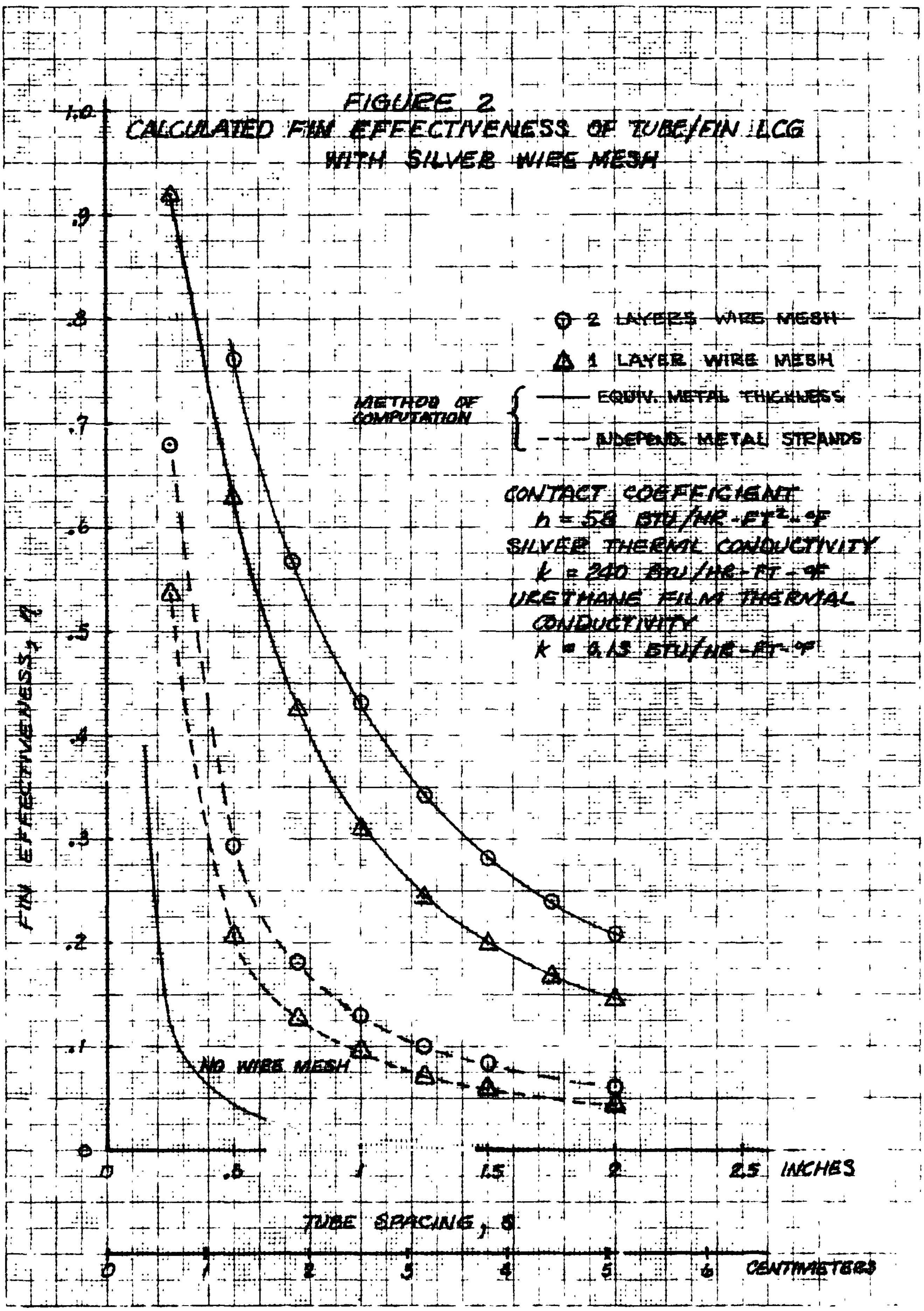


FIGURE 2
CALCULATED FIN EFFECTIVENESS OF TUBE/FIN LCG
WITH SILVER WIRE MESH
2 LAYERS WIRE MESH
1 LAYER WIRE MESH
METHOD OF COMPUTATION
EQUIV. METAL THICKNESS
INDEPEND. METAL STRANDS
CONTACT COEFFICIENT
h = 58 BTU/HR-FT²-°F
SILVER THERMAL CONDUCTIVITY
k = 240 BTU/HR-FT-°F
URETHANE FILM THERMAL CONDUCTIVITY
k = 0.13 BTU/HR-FT-°F
NO WIRE MESH
FIN EFFECTIVENESS, η
TUBE SPACING, S
INCHES
CENTIMETERS

FIGURE 3

CALCULATED HEAT CONDUCTED THROUGH TUBE WALL

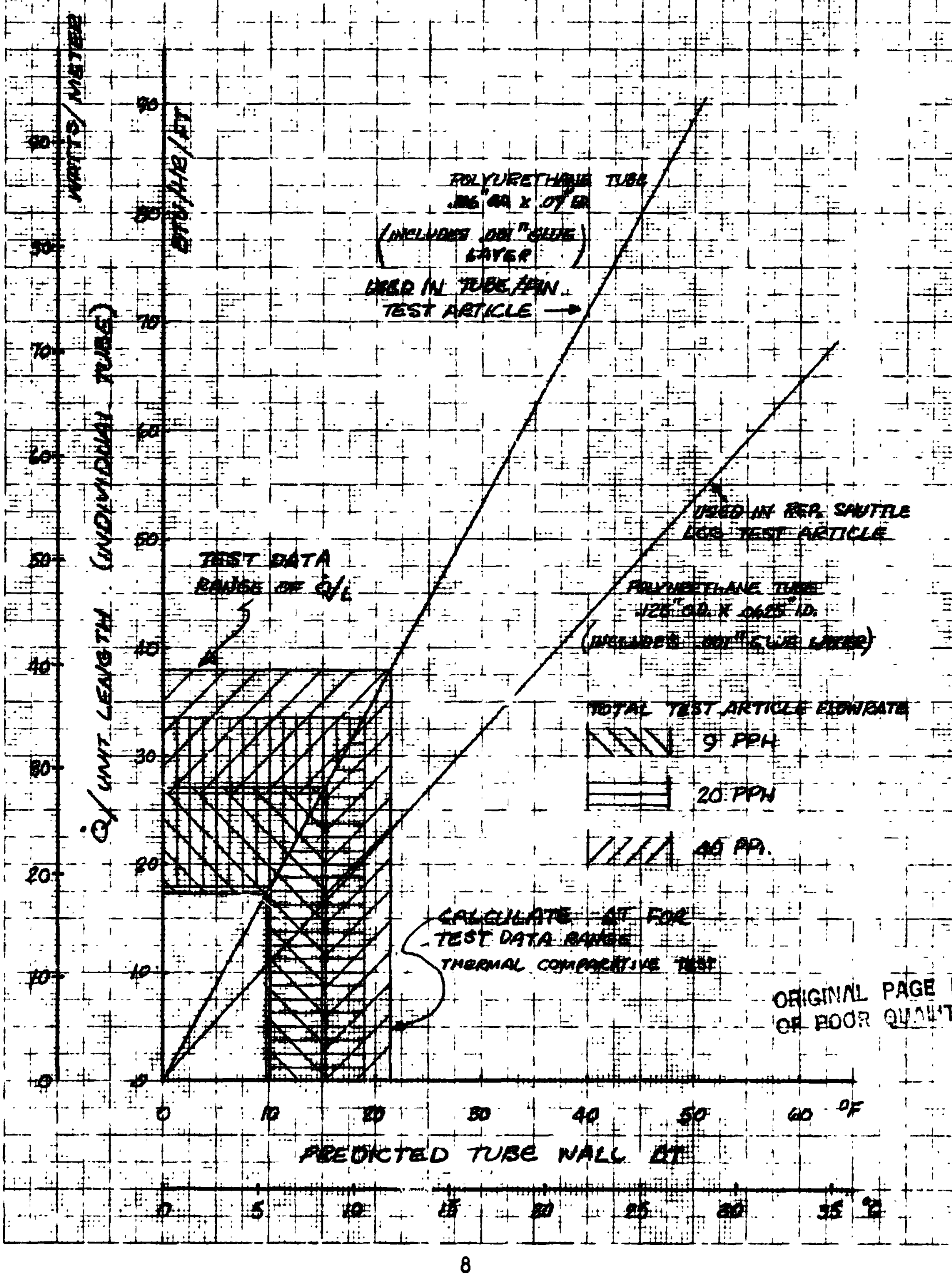


TABLE 2 FABRICATED ARTICLES

GARMENT	DESCRIPTION	DISPOSITION
HEAD COOLER NO. 1	NO METAL MESH, ADHESIVE BONDED SEAMS, NO COMFORT LINER	SCRAP
HEAD COOLER NO. 2	NO METAL MESH, HEAT SEALED SEAMS, NO COMFORT LINER	SCRAP
HEAD COOLER NO. 3	NO METAL MESH, HEAT SEALED SEAMS, NO COMFORT LINER	SCRAP
HEAD COOLER NO. 4	NO METAL MESH, HEAT SEALED SEAMS, NO COMFORT LINER	SCRAP
HEAD COOLER NO. 5	METAL MESH, HEAT SEALED SEAMS, LYCRA LINER	DELIVERED - NASA AMES
HEAD COOLER NO. 6	METAL MESH, SEAMS SOWN, T-SHIRT LINER	VOUGHT
HEAD COOLER NO. 7	METAL MESH, SEAMS SOWN, T-SHIRT LINER	VOUGHT
HEAD COOLER NO. 8	METAL MESH, SEAMS SOWN, LYCRA LINER	DELIVERED - NASA AMES
HEAD COOLER NO. 9	METAL MESH, SEAMS SOWN, TUBING LENGTH DOUBLED, T-SHIRT LINER	DELIVERED - NASA AMES
NEONATE (PREMATURE)	METAL MESH, LEFT IN FLAT PATTERN	DELIVERED - NASA AMES
NEONATE (FULL TERM)	METAL MESH, LEFT IN FLAT PATTERN	DELIVERED - NASA AMES
TEST ELEMENT	METAL MESH, 11 PARALLEL TUBES	DELIVERED - NASA AMES
SHUTTLE LCG TEST ELEMENT	36 PARALLEL TUBE (REPRESENTATIVE SPACING)	DELIVERED - NASA AMES

FIGURE 4

HEAD COOLER FABRICATION

MAJOR STEPS OF FABRICATION

- CUT OUT FLAT PATTERNS
- THERMOFORM SERPENTINE TUBING
- CLEAN LAYUP COMPONENTS
- PREPARE ADHESIVE SYSTEM
- SPRAY ADHESIVE ON LAYUP COMPONENTS
- VACUUM BAG ASSEMBLED COMPONENTS
- THERMAL CURE ADHESIVE
- SEW FLAT PATTERN INTO GARMENT SHAPE
- ATTACH COMFORT LINER

FIGURE 5
GARMENT FLAT PATTERN

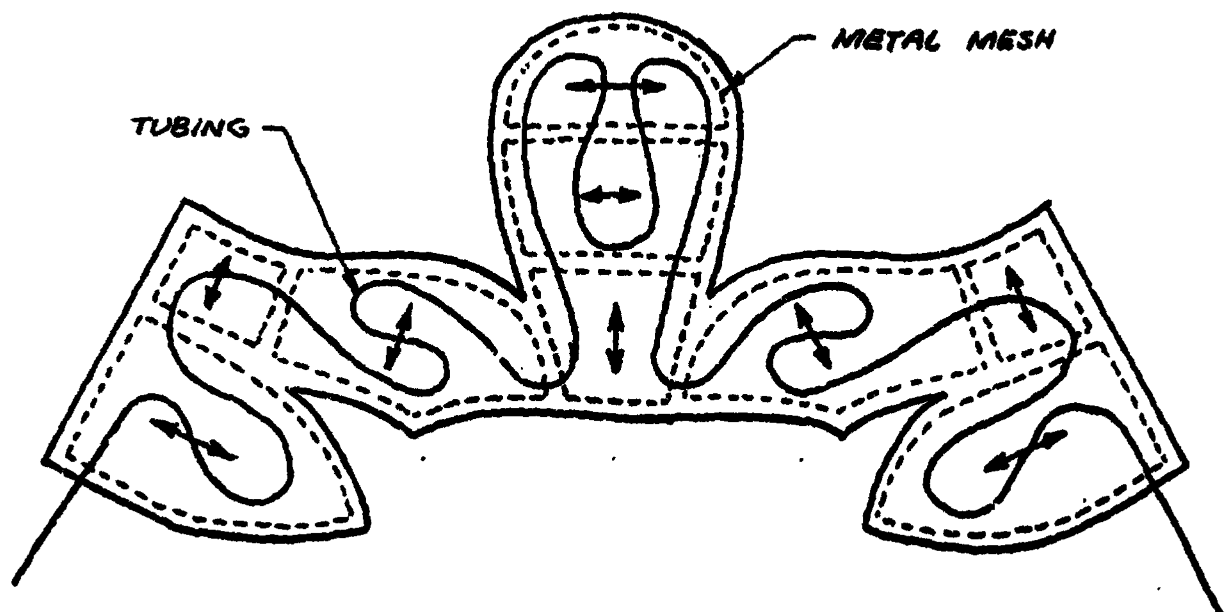
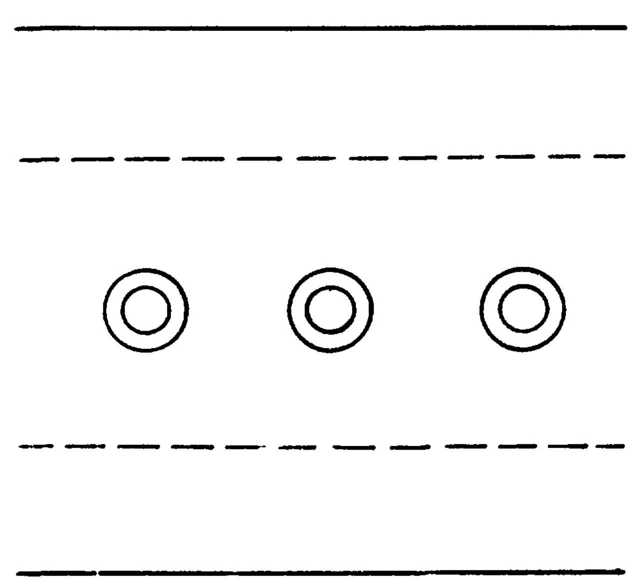


FIGURE 6
HEAD COOLER LAYUP
(CROSS - SECTION)



B. F. GOODRICH TF410, 1½ MIL.
POLYURETHANE FILM

EXMET 3 Ag 5 - 2/0 FLATTENED
EXPANDED METAL MESH

J. P. STEVENS MP-1880, .07" I.D. x .106" O.D.
POLYURETHANE TUBING

EXMET 3 Ag 5 - 2/0 FLATTENED
EXPANDED METAL MESH

B. F. GOODRICH TF410, 1½ MIL.
POLYURETHANE FILM

BONDED TOGETHER WITH NORDBAK 50-93 RESIN SYSTEM

Fabrication of head coolers by the tube/fin method results in garments which are elastic, conform to the head, and are durable as summarized in Figure 7. Tests on similarly constructed test elements demonstrated the head coolers effectiveness. (See Section 3.4).

Appendix A contains laboratory notes which detail the fabrication effort.

3.4 Thermal Comparison Test

A thermal comparison test was conducted on Flexitherm, Shuttle LCG, and tube/fin test articles as indicated in Figure 8. NASA supplied the Flexitherm test article but the Shuttle LCG test article was made by Vought. Thermal effectiveness is related to the flow path spacing because the transport fluid is brought into closer contact with more of the heated surface as the tube spacing is reduced.

Heat absorption data for the three test articles are presented in this section and further test description and data can be found in Appendix C. Referring to Figure 9, the plot of heat absorption rate for the Flexitherm test article, general trends can be identified which apply to all the test articles. As the inlet temperature increases, the ΔT between the fluid and plate decreases and the potential for heat transfer is reduced. Lowering the plate temperature has the same effect since the fluid-to-plate ΔT is reduced. Increasing the total transport flow through the test articles effectively lowers the average fluid temperature which increases the fluid-to-plate ΔT and increases the heat transfer.

The Flexitherm test article had the highest heat absorption rate due to the small tube spacing (.2 inch) and thin tube wall (.010 inch). The representative Shuttle LCG test article has a slightly wider tube spacing (.32 inch) and a considerably thicker and more rigid tube wall (.031 inch) and both factors work to give a heat absorption rate lower than was obtained with the Flexitherm test article, as shown in Figure 10.

As shown in Figure 11, the tube/fin LCG test article exhibits all the trends discussed above but the data has more scatter, unexplainably, for the higher plate temperature. It had the lowest heat absorption rate. Tube spacing (.9 inch) is four and one-half times greater than

FIGURE 7

FABRICATION RESULTS

- TOTAL GARMENTS FABRICATED
  - 9 HEAD COOLERS (#5 - 9 WITH LINERS)
  - 2 NEONATE GARMENTS (W/O LINER)
- ELASTIC GARMENT
- BODY CONFORMING
- GOOD PEEL STRENGTH
- STRONG SEAMS (SEWN)
- GOOD FEEL OF GARMENT LINER
- REVERSIBLE GARMENT
- THERMALLY EFFECTIVE GARMENT

FIGURE 8

THERMAL COMPARISON TEST

- TEST COMPARED
  - FLEXITHERM
  - REPRESENTATIVE SHUTTLE LCG
  - VOUGHT TUBE/FIN
- THERMAL EFFECTIVENESS DIRECTLY RELATED TO FLOW PATH SPACING
  - FLEXITHERM - .2 INCH
  - SHUTTLE LCG - .32 INCH
  - TUBE/FIN - .90 INCH

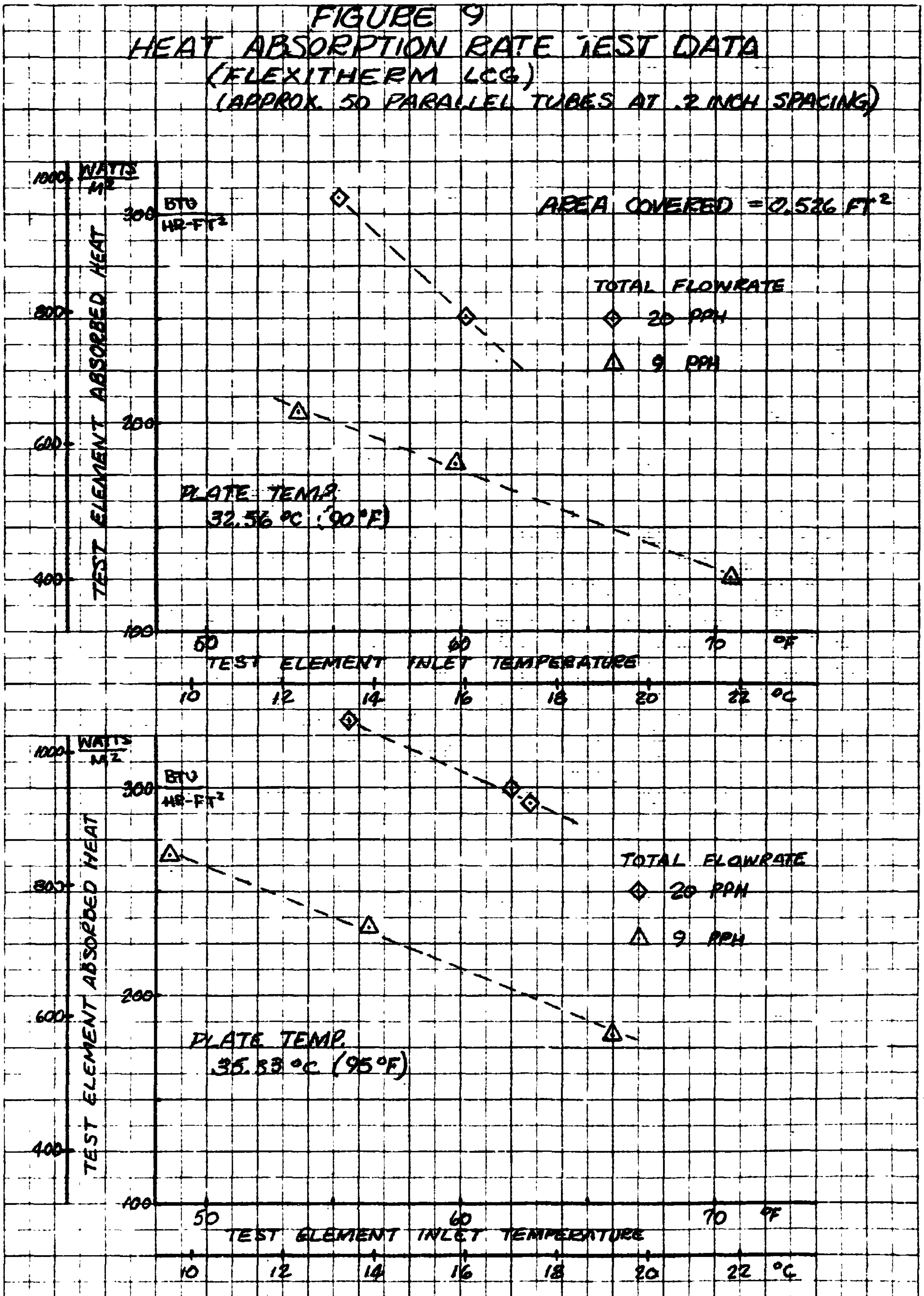
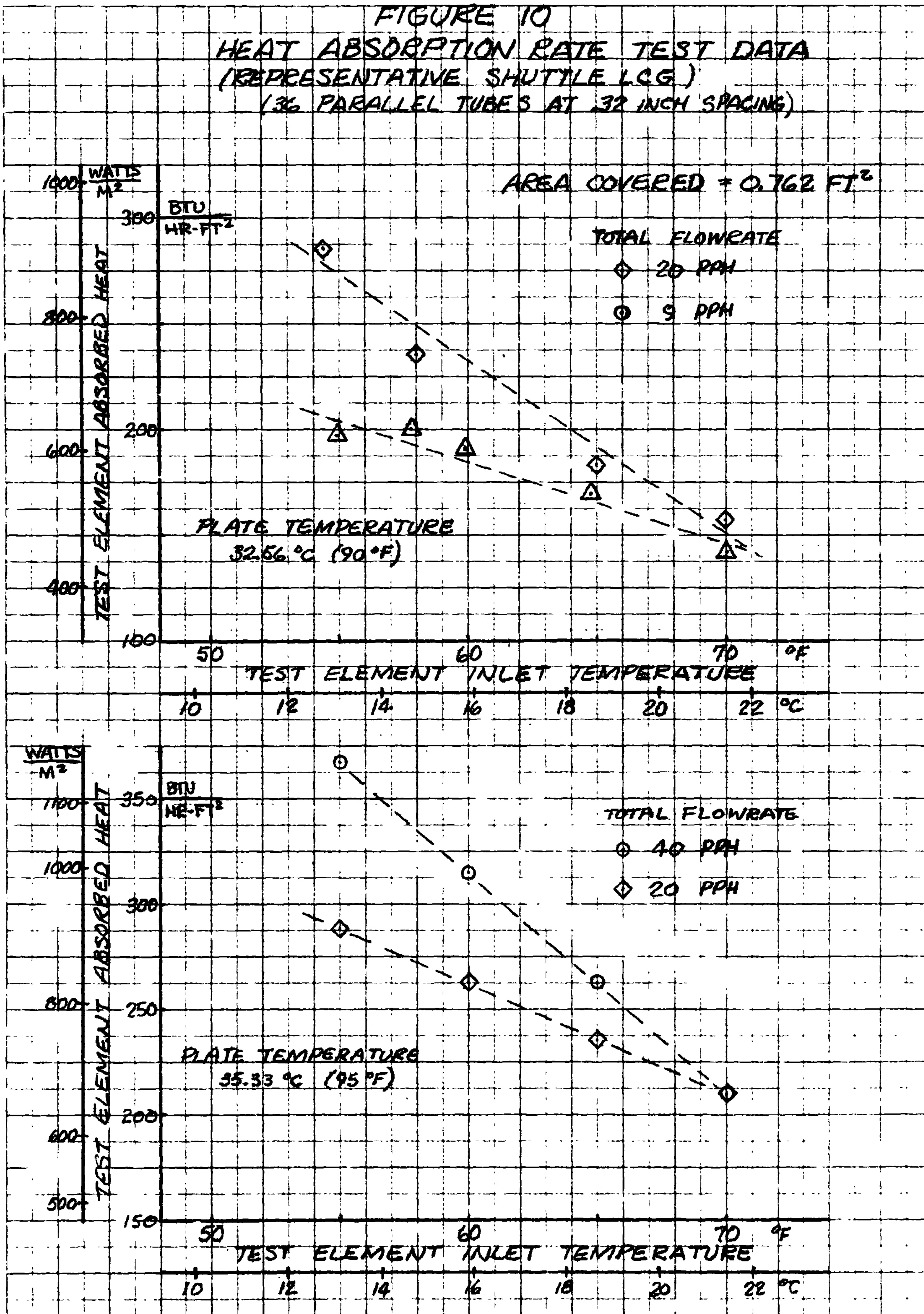


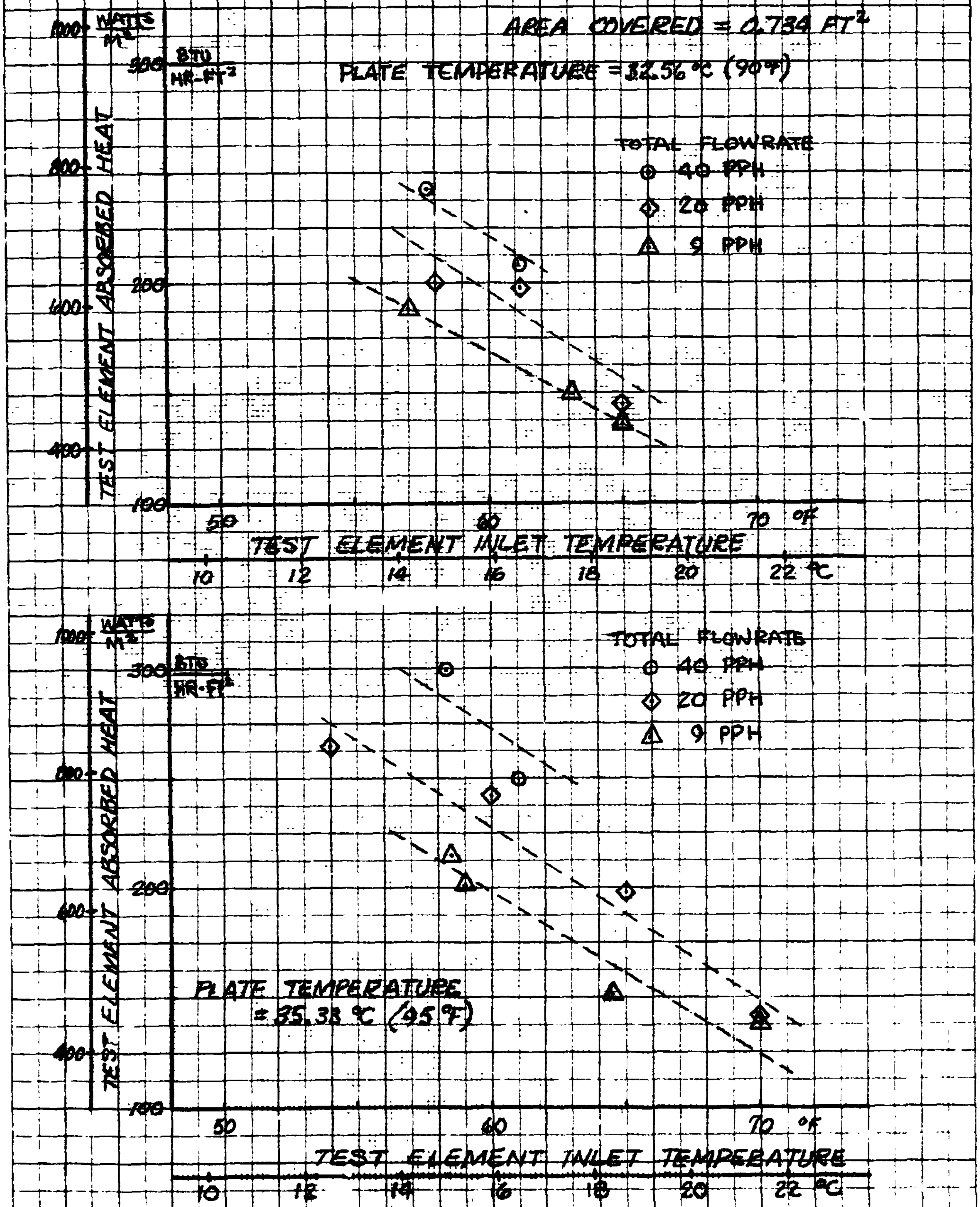
FIGURE 9
HEAT ABSORPTION RATE TEST DATA
(FLEXITHERM LCG)
(APPROX. 50 PARALLEL TUBES AT .2 INCH SPACING)



461510

K&E 10 X 10 TO THE CENTIMETER
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 11
HEAT ABSORPTION RATE TEST DATA
(TUBE/FIN LCG CONCEPT)
(11 PARALLEL TUBES AT 9 INCH SPACING)



the Flexitherm sample. The combination of tube wall thickness (.016 inch) and film thickness (0.0015 inch) give an effective thickness intermediate between the Flexitherm and the thick wall Shuttle LCG tubing. Because of the presence of the metal mesh the tube/fin LCG had the greatest rigidity in the tube area and the least tube contact (due both to its rigidity and the localized bumps in the areas of the metal strands).

Future tests should be performed with a test device having a more compliant surface than the heated aluminum sheet used in the present work. Heat transfer contact area with the aluminum sheet is highly dependent on the softness of the transport tubing layup, as opposed to the actual end use against the human body which would be much more compliant. Present results appear to be consistently biased in favor of the softer layups.

3.5 Production Cost Analysis

This section contains results of a production cost analysis, both manhours and materials, for fabricating six units each of three different garments, as summarized in Figure 12. Although the head cooler can be made in eight (8) hours of work, the actual fabrication must take place over two days because the sprayed adhesive must have time to outgas. All cost values were arrived at assuming current methods and procedures. The material costs do not include the expense of minimum buy requirements. Minimum buy requirements have the greatest impact on the "head cooler only" adding approximately $800 to the materials cost for the six garments. Similarly, the head/vest cooler material costs are increased $300 for six garments. The full body/head cooler uses sufficient material that minimum buy requirements are not a factor.

Details of the production cost analysis are presented in Appendix B. Not included in the production costs are development costs for the head/vest cooler and full body/head cooler required to bring these cooler garments to the same point of development as the head cooler of which numerous garments have been fabricated.

FIGURE 12

PRODUCTION COST ANALYSIS SUMMARY

- HEAD COOLER
  - 8 HOURS/UNIT BASED ON 6 UNITS
  - $400 MATERIALS FOR 6 UNITS
- HEAD/VEST COOLER
  - 12 HOURS/UNIT BASED ON 6 UNITS
  - $1500 MATERIALS FOR 6 UNITS
- FULL BODY/HEAD COOLER
  - 20 HOURS/UNIT BASED ON 6 UNITS
  - $2800 MATERIALS FOR 6 UNITS

4.0 STATE-OF-THE-ART FOR TUBE/FIN GARMENTS

The work performed under this program shows that a tube/fin garment can be fabricated from commercially available materials. The garment is flexible and elastic and conforms to the head. Garment layup can be made as a flat pattern which greatly simplifies fabrication. Stitching the garment seams provides a simple method of closing the garment without elaborate tooling.

5.0 RECOMMENDATION FOR FUTURE WORK

Figure 13 gives areas where further work is recommended. Additional tube/fin test elements could be made to optimize tube spacing. Better head cooler patterning is recommended to improve garment compatibility with communication headsets, face masks, etc. The tube/fin LCG concept has been significantly advanced under the reported work and fabrication of garments for other areas (upper torso) of the human body are recommended. Some areas of fabrication could be made easier if more sophisticated tooling were available. It is recommended that the fabrication procedure be reviewed for areas where tooling would speed fabrication and improve the end product.

FIGURE 13

RECOMMENDATION FOR FUTURE WORK

- IMPROVED TUBE/FIN ELEMENT TESTING
- IMPROVED COVERAGE BY HEAD COOLER GARMENT
    - BETTER PATTERNING
    - CHIN STRAPS
- FABRICATION OF A VEST COOLING GARMENT
- ADVANCED TOOLING TO IMPROVE FABRICATION
- HUMAN SUBJECT TESTING (AT ARC)

APPENDIX A

LABORATORY NOTES

TUESDAY 1/25/77

MADE POLYURETHANE FILM ELEMENT

MIXED 25-98 ADHESIVE (NORDBAK EPOXY)

25 gm Resin
25 gm Hardener
30 ml TOLUENE (DILUENT)

80 ml of ADHESIVE SOLUTION (1:1:1.2)

ELEMENT COMPOSITION (RE-MAKE OF ELEMENT IN BAD CURE CYCLE)

TF 322 1½ mil
3 Ag 5 - 2/0
MP - 1880 — 25-98 ADHESIVE
3 Ag 5 - 2/0
TF 322 1½ mil

SPRAYED FILM AND MESH WITH EPOXY SOLUTION AND ALLOWED SPRAYED PART TO STAND FOR 2 HOURS BEFORE BAGGING.

ACCELERATED CURE USED: 2 HOURS AT 150°F

RESULTS: ELEMENT IS GOOD
BETTER ELASTICITY THAN PREVIOUSLY
WIRE MESH LIMITS STRETCH

ORIGINAL PAGE IS OF POOR QUALITY

WEDNESDAY 1/26/77

MADE LATEX SAMPLE

5 MIL LATEX SHEET
VITON L-31 ADHESIVE
3 Ag 5 - 2/0 WIRE MESH
1/8" O.D. LATEX TUBING
VITON L-31 ADHESIVE
5 MIL LATEX SHEET

ADHESIVE WAS MIXED 5/24/76 ORIGINALLY AND RE-STIRRED TO RECOVER THE DISPERSION.

SPRAYED THE ADHESIVE AND IMMEDIATELY BAGGED THE LAYUP BECAUSE ANOTHER USER REQUIRED THE OVEN FOR SET-UP AND OVERNIGHT BAKING.

RESULTS:

THE LATEX SHEETING PEELS APART EASILY AND APPEARS TO HAVE BUBBLES IN ADHESIVE. THE ADHESIVE WAS FOAMY WHEN SPRAYED AND MAY HAVE CAUSED THE BUBBLES OR PERHAPS THE SPRAYED SHEETING REQUIRED A LONGER OUTGASSING TIME.

THURSDAY 1/27/77

SPRAYED LATEX ADHESIVE ON LATEX SHEET TO TEST THE CURE AT ROOM TEMPERATURE OVERNIGHT.

THE VITON L-31 LATEX DISPERSION HAD SMALL UNDESOLVED LATEX PARTICLES WHICH CLOGGED THE "JET PAK" NOZZLE. I STRAINED THE PARTICLES OUT AND SPRAYED THE REMAINING LIQUID.

RESULTS:

VITON L-31 DID NOT ADHER WELL TO THE LATEX SHEET. THE L-31 SPLIT DURING CURE AND PEELS EASILY FROM THE LATEX SHEET.

ANALYSIS:

LATEX CONTAINS A BINDER (POWDER) WHICH CAN NOT BE REMOVED AND EFFECTIVELY PREVENTS BONDING.

MONDAY 1/31/77

TF410 / 50-93 MAT'LS COMPATIBILITY CHECK
MIX NORDBAK 50-93 EPOXY (BLK)

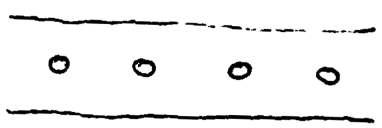
BY WEIGHT —		BY VOLUME —		
10 gm	RESIN	1 PART	RESIN	20 ml *
8.7 gm	HARDENER	1 PART	HARDENER	20 ml
		1 PART	TOLUENE	20 ml

— OMIT WIRE FOR THIS ELEMENT —
DEGREASE TF410 FILM AND TUBING WITH TOLUENE

SPRAY FILM WITH EPOXY
IF TOLUENE IS USED AS EPOXY DILUTENT, LET COMPONENTS OUTGAS FOR 2 HOURS BEFORE VACUUM BAGGING.

PREPARE VACUUM BAG —

LAYUP COMPOSITION



TF410 FILM
MP1880 TUBING
TF410 FILM

CURE: 45 min. AT 250°F (121°C)

RESULTS: GOOD PEEL STRENGTH
GOOD ELASTICITY (NO WIRE MESH)
FILM IS WRINKLED AT THE 180° BENDS

* 20 ml is the smallest graduation on plastic beaker

WEDNESDAY 2/9/77

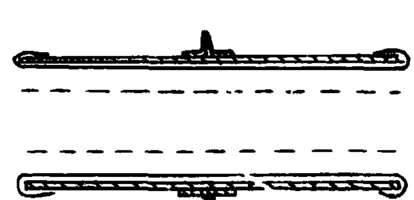
1. MADE 2 TEST ELEMENTS USING 2 MIL TF410 FILM WITH NORDBAK 25-98 ADHESIVE.

1A		1B
	TF410	
	3 Ag5-2/0	
	MP-1880	
	3 Ag5-2/0	
	TF410	
	COMFORT LINER	NONE

2. TRIED TO SPRAY "25-98" WITHOUT DILUENT. ADHESIVE IS TOO VISCOUS TO BE PULLED UP THE FEEDER TUBE OF JET-PAK. SPRAYED OKAY WITH TOLUENE ADDED

ADHESIVE MIX: 12.5 GM RESIN
12.5 GM HARDENER
10.0 ML TOLUENE

3. TO FACILITATE LAYUP PROCEDURE, I TAPED THE FILM TO SLIGHTLY UNDERSIZED PIECES OF CARDBOARD BEFORE I CLEANED (DEGREASED) THE FILM WITH 80% TRIC / 20% METHANOL SOLUTION. THE CARDBOARD WAS REMOVED PRIOR TO BAGGING.



THIS PROCEDURE, ALTHOUGH TIME CONSUMING IN THE EARLY STAGES, ELIMINATES MUCH OF THE FRUSTRATION OF POSITIONING THE FILM AFTER ADHESIVE WAS APPLIED. ONE NEGATIVE ASPECT OF ROLLING THE FILM BEHIND THE CARDBOARD IS THAT THE EDGES OF THE FILM DO NOT GET COATED WITH ADHESIVE.

RESULTS: GENERALLY NOT GOOD
POOR PEEL STRENGTH

COMMENTS –

AFTER ATTEMPTING TO SPRAY THE "25-98". WITHOUT A DILUENT, TOLUENE WAS ADDED BUT EVIDENTLY DID NOT GET MIXED WELL WITH THE ALREADY MIXED (2 PART) EPOXY. WHEN THE MIXTURE WAS SPRAYED IT WAS MOSTLY DILUENT.

FRIDAY 2/11/77

1. MAKE VARIATION OF ELEMENT #3

TF410 2 MIL
3 Ag 5 - 2/0
MP-1880
TF410 2 MIL

USE NORDBAK 50-93 ADHESIVE
BY VOLUME: 5 ml RESIN
5 ml HARDENER
10 ml TOLUENE

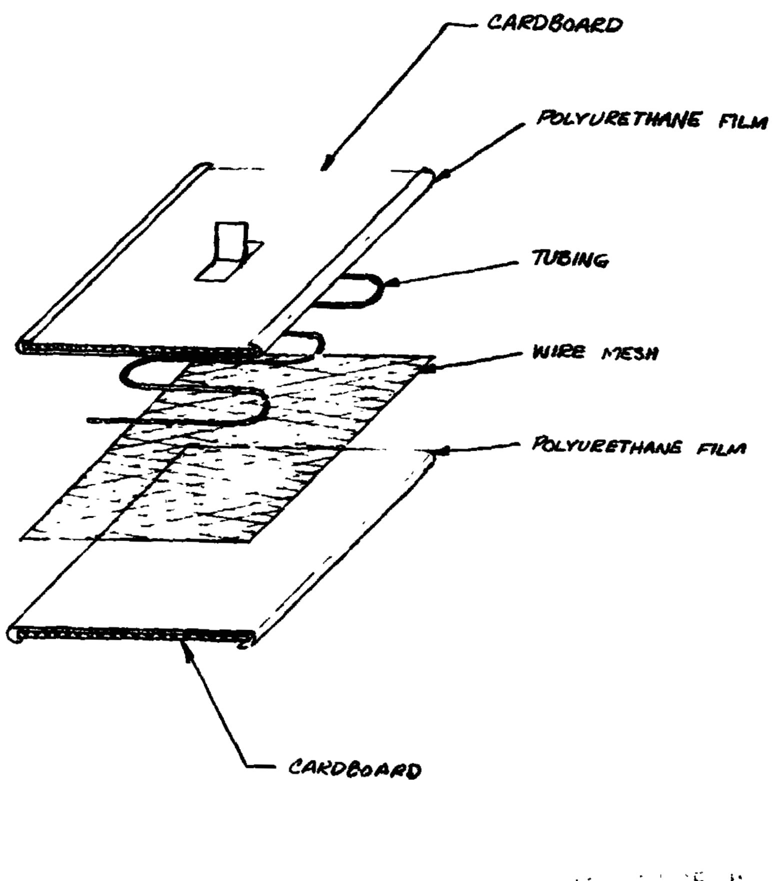
2. THE WIRE MESH (3 Ag 5 - 2/0) WAS STRETCHED IN THE LWD DIRECTION WHICH REDUCED THE SWD.
AVERAGE SWD = .05"

RESULTS: GOOD PEEL STRENGTH
GOOD ELASTICITY
CURE CYCLE WAS 2X THE RECOMMENDED LENGTH BUT DID NOT REDUCE THE ELASTICITY APPRECIABLY

2/11/77

ATTACH THE POLYURETHANE FILM TO CARDBOARD WITH CELLOPHANE TAPE.

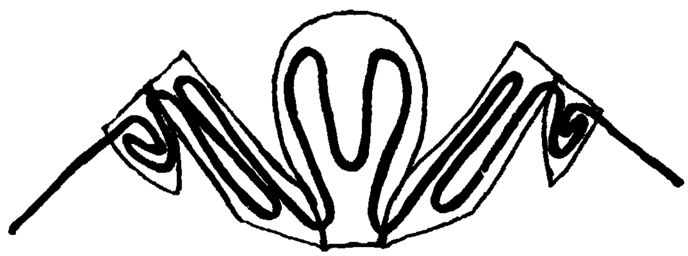
CARDBOARD HOLDS FILM FLAT & SMOOTH DURING DEGREASING, ADHESIVE SPRAYING AND ELEMENT POSITIONING.



FRIDAY 18 FEB 77

HEAD COOLER —

FLAT PATTERN



1ST ATTEMPT WILL BE WITH
- 1½ mil TF322
- Nordbak 50-93
- NO WIRE MESH
- MP-1880 TUBING

TUBING WILL BE THERMOFORMED TO FACILITATE FABRICATION

THE Ag WIRE MESH WILL BE OMITTED TO CONSERVE SCARCE MATERIALS

1ST ATTEMPT WILL IRON THE BUGS OUT OF THE FAB. PROCESS

TUESDAY 22 FEB 77

LABORATORY WORK

LAID OUT THE SERPENTINE TUBE PATTERN FOR THE HEAD COOLER.

TUBE LENGTH = 8 ft.

THERMOFORMED TUBING @ 250°F FOR 90 MIN.
(CONSIDERABLE SHRINKAGE)

MOUNTED THE POLYURETHANE FILM (TF322 - 1½ mil) ON CARDBOARD PATTERNS FOR CLEANING AND ADHESIVE APPLICATION.
- CLEANING DONE WITH TOLUENE -

THURSDAY 24 FEB 1977

THERMOFORMED TUBING FOR 90 min @ 250°F
THIS IS A SECOND ATTEMPT — TRYING TO OVERCOME THE SHRINKAGE.

SOME SUCCESS - BETTER THAN EARLIER ATTEMPT
TUBING DOES NOT MAINTAIN THE ORIGINAL FORM LAID OUT

TUBING LENGTH = 11 ft.

MIXED NORDBAK 50-93 by volume

20 ml	RESIN
20 ml	HARDENER
10 ml	TOLUENE (DILUENT)

THIS (50 ml) WAS BARELY ENOUGH TO SPRAY ALL THE FILM SECTIONS.
-MIX LARGER QUANTITY* OF EPOKY IN THE FUTURE OR INCREASE DILUENT QUANTITY -

* LARGER QUANTITY NOT NECESSARY - APPLICATION WAS EXCESSIVE - REDUCE APPLICATION THICKNESS AND 30 ML WILL COVER THE FILM AREA.

FRIDAY 25 FEB. 1977

LEITH AND I FABRICATED HEAD COOLER FLAT PATTERN ELEMENT

SOME IMPROVEMENTS/CHANGES WERE IMMEDIATELY IDENTIFIED.

1. Reduce the thickness of the adhesive layer sprayed on the film

2. Do not use polyethlene with cure cycles of 250°F

3. Vent the tubing out of the vacuum bag

4. Consider making the film in single piece instead of individual components

5. Experiment with heat sealing

Results:

1. GOOD ELASTICITY
2. GOOD PEEL STRENGTH
3. TUBING FLATTENED - PASSAGE CLOSED
4. ADHESIVE ON EXTERIOR - CAN BE CLEANED
5. BAGGING MAT'L STUCK TO ARTICLE

TUESDAY 1 MAR 1977

EXPERIMENTING WITH HEAT SEALING

HEAT SEALING THE HEAD COOLER SEAMS WAS HAMPERED BY THE EXCESS ADHESIVE WHICH COATED THE SEAM AREA.

CLEANED THE SEAM AREA WITH TOLUENE AND TRIED AGAIN.

THE SECOND ATTEMPT AT HEAT SEALING MET WITH GREATER SUCCESS ALTHOUGH THE SEAM STRENGTH ACHIEVED WAS VARIED AND MARGINAL IN MOST AREAS.

OPERATOR TECHNIQUE AND THE HEAT SEALING MACHINE WERE LESS THAN OPTIMUM. A SMALL MACHINE MIGHT PERMIT FOLLOWING THE SEAM CURVATURE.

THE 4 LAYERS OF 1.5 MIL FILM WERE EASILY OVERHEATED - CREATING A WEAK JOINT. THE FILM THICKNESS (NO. OF LAYERS) WASN'T UNIFORM ALONG THE SEAMLINE WHICH CREATED THE NEED FOR CONTINUAL SETTING CHANGES.

—o—

STARTING WITH THE HEAT SEAL SEAMS, GUSSET MATERIAL (TF322) WAS GLUED ON THE CONVEX SIDE OF THE HEAD COOLER. USE UNDILUTED NORDBAK 25-98 ADHESIVE APPLIED TO SEAM AREA WITH A COTTON SWAB

NORDBAK 25-98 ADHESIVE CURES OVERNIGHT AT ROOM TEMPERATURE

VACUUM BAG NOT SEALED ABSOLUTELY BUT POLYETHLENE IS HOLDING MATERIAL TIGHT FOR OVERNIGHT CURE

WEDNESDAY 2 MAR 1977

REMOVED HEAD COOLER GARMENT FROM VACUUM BAGGED HEAD MOLD.

THE GUSSET MATERIAL SLIPPED BUT GENERALLY COVERED THE SEAM AREA. WRINKLING OF THE GUSSET MATERIAL WAS VERY BAD.

THE SEAM STRENGTH WAS INCREASED BY ADDING THE GUSSET MATERIAL.

THIS TECHNIQUE IS DIFFICULT TO PERFORM DUE TO:

1. VACUUM BAG DIFFICULT TO SEAL
2. GUSSET MAT'L DIFFICULT TO KEEP IN POSITION
3. GUSSET MAT'L WRINKLES DURING BAGGING

THURSDAY 3 MAR 1977

MAKE A SECOND FLAT PATTERN HEAD COOLER

USE 1 ½ mil TF322 *FILM*
NORDBAK 50-93 *ADHESIVE*
NO WIRE MESH
MP-1880 *TUBING* .07" I.D. X .106" O.D.

MAKE FLAT PATTERN AS SINGLE COMPONENT.

THERMOFORM TUBING - 12 feet length -

NORDBAK 50-93 (*BY VOLUME*)
10 ml *RESIN*
10 ml *HARDENER*
10 ml *TOLUENE* (diluent)

DAUBBED SPRAYED ADHESIVE WITH "KIMWIPE" TISSUE TO REMOVE EXCESS ADHESIVE AND CREATE MORE UNIFORM LAYER OF ADHESIVE (LOOKS GOOD)

THIS IS SUFFICIENT ADHESIVE TO COVER THE PATTERN AND WIRE MESH WHEN THE LATTER IS USED

FRIDAY 4 MAR 1977

FABRICATED SECOND HEAD COOLER
-USED MAT'LS LAB OVEN -
GOOD ELASTICITY AND PEEL STRENGTH FOR GARMENT

THE SINGLE COMPONENT FLAT PATTERN WORKED WELL.

THE SERPENTINE TUBE DIDN'T FLATTEN AS OCCURRED PREVIOUSLY, HOWEVER THERE IS TOO MUCH TUBING WHICH HAMPERS HEAT SEALING OF SEAMS.

OBSERVATIONS -

NEED SMALLER, CURVED HEAT SEALING MACHINE.

NEED TO REDUCE THE LENGTH OF TUBING IN CROWN AREA

RUNNING LOW ON TF322 SAMPLES

MONDAY 7 MAR 1977

PREPARED FLAT PATTERN HEAD COOLER (#3)

SINGLE COMPONENT

3 mil TF410 FILM
Nordbak 50-98 ADHESIVE *
NO WIRE MESH
MP-1820 TUBING

REVISED TUBING ROUTING

* 10 ml. OF MIXED ADHESIVE WAS LEFT-OVER FROM ADHESIVE APPLICATION OF 3 MAR 1977. USED 10 ml OF TOLUENE TO DILUTE AND SPRAYED ADHESIVE AS USUAL. NOTICED IMMEDIATELY ADHESIVE WAS MORE TACKY THAN A FRESH MIXTURE. TOLUENE SOAKED KIMWIPE USED TO EVEN OUT ADHESIVE.

ADHESIVE COATED FILM ALLOWED TO STAND OVERNIGHT TO OUTGAS TOLUENE

THERMOFORMED REVISED TUBE ROUTING – STILL USING APPROX. 12 FT TUBING LENGTH.

MIXED NORDBAK 25-98 ADHESIVE AND APPLIED IT TO #2 HEAD COOLER TO GLUE DOWN HEAT SEALED SEAM TABS. (NON-DILUTED)
VACUUM BAGGED GARMENT ON HEAD MOLD** AND CURED IN OVEN AT 130°F FOR 90 MIN – WHICH WAS INSUFFICIENT TO CURE ADHESIVE. USED RUBBER BANDS TO HOLD SEAMS AGAINST MOLD DURING OVERNIGHT AMBIENT TEMPERATURE CURE.

** POLYSTYRENES HAVE LOW SERVICE TEMPERATURE 150-170°F THEREFORE I KEPT CURE CYCLE BELOW NORMAL AND ADHESIVE DID NOT CURE OUT

TUESDAY 8 MAR 1977

FABRICATED HEAD COOLER #3

ADHESIVE ON FILM CURING OUT - TUBING WILL NOT SLIP AROUND EASILY. POSITIONING MADE MORE DIFFICULT.

SINGLE COMPONENT FILM SIMPLIFIES LAY-UP.
FILM AND TUBING CLEANED WITH TOLUENE
USED ENGR MAT'LS LAB OVEN FOR THERMAL CURE - 250°F FOR 45 min

RESULTS:

* POOR PEAL STRENGTH
ELASTICITY OKAY (RECALL 3 mil FILM USED)

THIS MAY BE DUE TO DILUTING PARTIALLY CURED ADHESIVE ORIGINALLY MIXED 3 MAR 1977.

INSPECTION OF HEAD COOLER #2

MECHANICAL HOLD DOWN TO SEAL SEAMS REMOVED.
ADHESIVE STILL TACKY AFTER LOW TEMPERATURE (AMBIENT) OVERNIGHT CURE. - DO NOT UNDERSTAND NON-CURING. - PERHAPS THE APPLICATION WAS THICKER THAN NORMAL DUE TO SWABBING ADHESIVE ON SEAMS.

CREATING STRONG AND NEAT SEAMS IS CURRENT PROBLEM AREA.

THURSDAY 10 MAY 1977

JOIN SEAMS OF NO. 3 HEAD COOLER

USE NORDBAK 25-98 MIXED 4.65 gm RESIN
4.65 gm HARDENER
(MIXED BY WT) TOT. 9.3 gm
NO DILUENT USED

VACUUM BAGGED GARMENT ON HEAD MOLD WITH LATEX SHEET

ACCELERATED CURE USED — 2 HRS AT 150°F IN ENGR MAT'LS LAB OVEN

RESULTS:

GOOD APPEARANCE – NEAT, FLAT

POOR PEEL STRENGTH – SEAMS SEPARATE EASILY, ADHESIVE CURED BUT MADE WEAK BOND.

ANALYSIS:

THE SEAM AREA WAS CLEANED WITH TOLUENE AND PERHAPS THE EPOXY WAS APPLIED TOO SOON THEREAFTER

THE ORIGINAL BAGGING (BLEED CLOTH) CREATING A WAFFLING OF THE FILM WHICH REDUCES THE ADHESIVE AREA WHEN JOINING THE SEAMS.

LATEX RUBBER HAS A RELEASE AGENT INTEGRAL WITH THE BASE MAT'L WHICH NEGATES THE ADHESIVE.

MONDAY 14 MAR 1977

PREPARE FLAT PATTERN FOR HEAD COOLER #4

USE 3 MIL TF410 FILM
DEGREASED WITH FULL-STRENGTH TOLUENE

THERMOFORMED TUBING - 10 FEET LENGTH -
- 2 HRS AT 250 °F -

TUESDAY 15 MAR 1977

MIXED NORDBAK 50-93 ADHESIVE	5 ML	RESIN
	5 ML	HARDENER
(MIXED BY VOLUME)	10 ML	TOLUENE

ADHESIVE SPRAYED THEN DAUBBED WITH "KIMWIPE"
TO EVEN OUT ADHESIVE AND REMOVE EXCESS.

THERMOFORMED TUBING CLEANED WITH TOLUENE

WEDNESDAY 16 MAR 1977

FABRICATED HEAD COOLER #4

USE ACCELERATED CURE - 250°F FOR 45 MIN.
(ENGR. MAT'LS LAB. OVEN)

RESULTS: NOMINAL PEEL STRENGTH
THE 3 MIL FILM SEEMS TO BE A FACTOR.
LAYUP IS SERVICEABLE IF EDGES CAN BE EFFECTIVELY SEALED.

WRINGLES IN FILM - ONE WRINGLE WAS SEVERE ENOUGH TO PINCH THE TUBING. TUBE FLOW CROSS-SECTION REDUCED 10%.

GOOD ELASTICITY

MONDAY 28 MAR 1977

MAKE LAP SEAMS

Use: 1. WOOD HEAD MOLD
2. Nordbak 50-93 ADHESIVE
    2.5 MIL RESIN
    2.5 MIL HARDENER
    NO DILUENT
3. LATEX SHEET - VACUUM BAG
4. CHEESE CLOTH - BLEED CLOTH
5. No. 3 HEAD COOLER FLAT PATTERN
6. ACCELERATED CURE 250°F FOR 45 MIN.

RESULTS:

SEAM STRENGTH - ONLY NOMINAL, CAN BE PEELED APART

SEAM APPEARANCE - WRINGLES, IF ADHESIVE BOND WAS BETTER THE SEAM APPEARANCES WOULD PASS

ANALYSIS:

IT APPEARS THAT THE ADHESIVE TECHNIQUE IS INADEQUATE

TUESDAY 19 APR 1977

FABRICATION OF REPRESENTATIVE <u>SHUTTLE LCG</u>

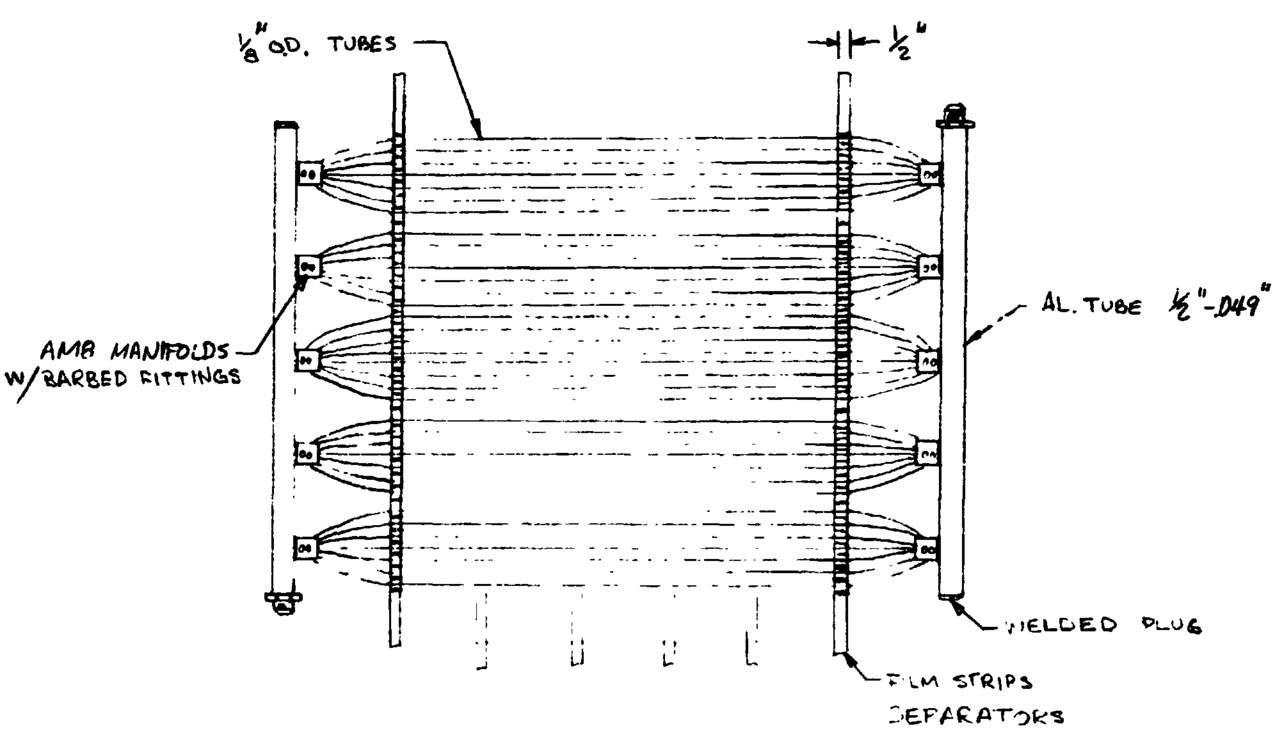
SPECIFICATION: $\frac{1}{8}$" O.D. x $\frac{1}{16}$" I.D. TUBING – $\frac{1}{4}$" SPACING

USE TUBING FROM STOCK

USE 3 MIL TF410 POLYURETHANE FILM FOR SEPARATORS

HEAT SEALED THE FILM AT ≅ 5/16" SPACING FOR 36 TUBES
THIS WILL CREATE A TEST ELEMENT ≅ 11½" WIDE.

PURCHASED MINIATURE FITTINGS TO CONNECT THE 36
TUBES TO MANIFOLDS.



WEDNESDAY 20 APR 1977

FABRICATION OF REPRESENTATIVE SHUTTLE LCG

CUT 36 LENGTHS OF TUBING 18 IN. LONG

MADE 7 - 1/2" WIDE POLYURETHANE STRIPS
HEAT SEALED AT 5/16 IN. INTERVALS.

THREADED THE 36 TUBE THRU 3 OF THE
FILM STRIPS.

THERMOFORMED A SERPENTINE TUBE FOR
THE VOUGHT TEST ELEMENT.

SERPENTINE TUBE CLEANED WITH TOLUENE.

TUESDAY 22 APR 1977

HEAT SEALING SEAMS ON HEAD COOLER #4

REF. INFO. HEAD COOLER
3 MIL TF410 FILM (2 LAYERS)
MP 1880 TUBING .106"/.07"
NO WIRE MESH
NORDBAK 50-93 ADHESIVE

EXPERIMENTED WITH HAND-HELD HEAT SEALER

THE PROPER PRESSURE (THUS HEAT) WILL SEAL THE 3 MIL FILM BUT WILL ALSO MELT THRU THE FILM. THE HEAT SEALER IS 75 WATT AND HAS A KNURLED WHEEL.

SEAMS ARE STRONG ALTHOUGH I BURNED THROUGH THE BASE MATERIAL IN SEVERAL PLACES.

WEDNESDAY 4 MAY 1977

1

PREPARATION FOR FABRICATION OF VOUGHT DESIGN
ADV. LCG TEST ELEMENT

CUT SILVER (3 Ag5-2/0 FLAT) WIRE MESH TO SIZE.
CLEANED THE TWO PIECES OF WIRE MESH
WITH TOLUENE.

CUT 1½ MIL TF410 FILM FOR TEST ELEMENT.
TAPED FILM TO CARDBOARD AND CLEANED
BOTH PIECES WITH TOLUENE

2

CUT AND BEGAN TO MOUNT 1½ MIL TF410
ON CARDBOARD PATTERNS FOR NO. 5
HEAD COOLER FLAT PATTERN.

PLAN TO FABRICATE NO. 5 HEAD COOLER AND
TEST ELEMENT FROM A SINGLE 50-93 ADHESNE
MIX.

THURSDAY 5 MAY 1977

MIX NORDBAK 50-93 ADHESIVE

10 ML RESIN
10 ML HARDENER
10 ML DILUENT (TOLUENE)

1

ADV. LCG TEST ELEMENT

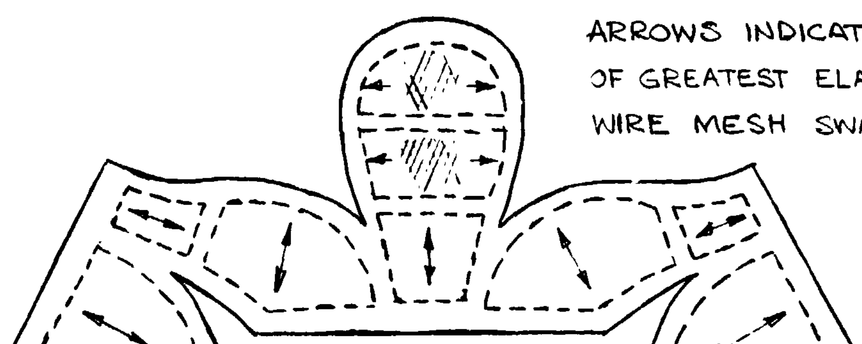
SPRAYED THE 1½ MIL TF410 FILM AND WIRE MESH WITH ADHESIVE - DAUBED ADHESIVE TO IMPROVE DISTRIBUTION ON FILM - SPRAYED ITEMS ALLOWED TO OUTGAS OVERNIGHT.

2

HEAD COOLER FLAT PATTERN #5

FINISHED MOUNTING 1½ MIL TF410 FILM ON CARDBOARD PATTERNS

CUT WIRE MESH PER PATTERN BELOW



ARROWS INDICATE DIRECTION OF GREATEST ELASTICITY OF WIRE MESH SWATCHES

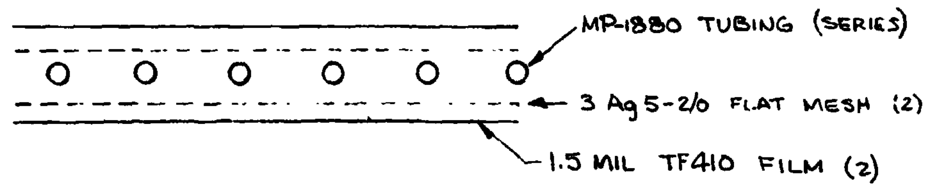
SPRAYED THE FILM (BUT NOT THE WIRE) WITH ADHESIVE AND DAUBED ADHESIVE TO IMPROVE DISTRIBUTION. ALLOWED THE ADHESIVE TO OUTGAS OVERNIGHT.

FRIDAY 6 MAY 1977

1

ADV. LCG TEST ELEMENT

ASSEMBLED THE TEST ELEMENT AS DESCRIBED BELOW



USE ACCELERATED CURE OF 45 MIN. AT 250°F FOR THE NORDBAK 50-93 ADHESIVE.

RESULTS: GOOD ELASTICITY AND PEEL STRENGTH...

2

HEAD COOLER NO. 5

ASSEMBLED THE HEAD COOLER FLAT PATTERN SAME CONSTRUCTION LAYUP AS USED FOR THE ADV. LCG TEST ELEMENT.

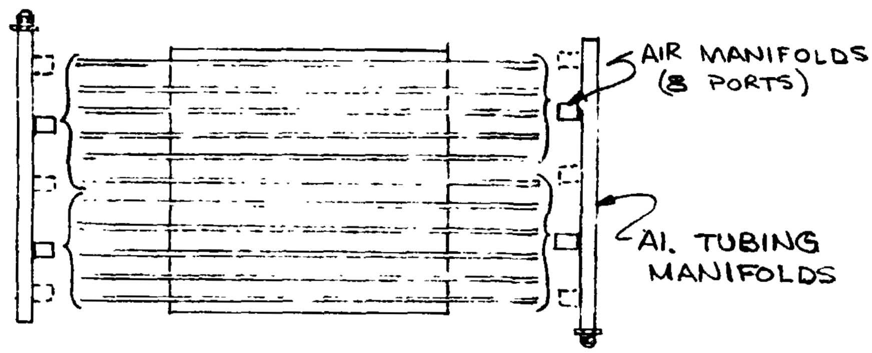
USED ACCELERATED CURE OF 45 MIN. AT 250°F FOR THE NORDBAK 50-93 ADHESIVE.

RESULTS: GOOD ELASTICITY AND PEEL STRENGTH... SERPENTINE TUBING DID NOT GET POSITIONED EXACTLY AS DESIRED.

MONDAY 9 MAY 1977

ADV. LCG TEST ELEMENT (PARALLEL FLOW)

PREPARED AND DEGREASED 1-1/2 MIL TF410 FILM AND SILVER WIRE MESH



TEST ELEMENT WILL REQUIRE THE USE OF THE MINIATURE BARBED FITTINGS AND AIR MANIFOLDS PURCHASED ORIGINALLY FOR THE REPRESENTATIVE SHUTTLE LCG TEST ELEMENT.

CUT ELEVEN LENGTHS OF TUBING AND CLEANED THEM WITH TOLUENE
TUBING IS .106 O.D. X .07 ID X 18" LONG.

TUESDAY 10 MAY 1977

ADV. LCG TEST ELEMENT (PARALLEL FLOW)

MIXED NORDBAK 50-93 ADHESIVE
- 5 ML RESIN
- 5 ML HARDENER
- 7 ML DILUENT (TOLUENE)

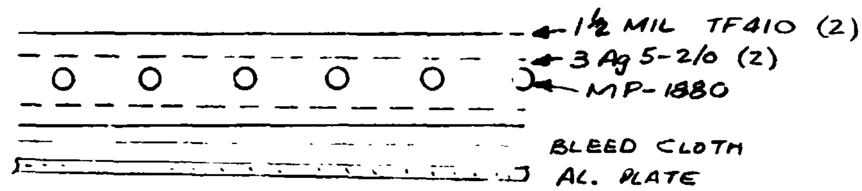
SPRAYED FILM AND WIRE MESH WITH ADHESIVE. DAUBED ADHESIVE ON FILM WITH "KIMWIPE" TO IMPROVE ADHESIVE DISTRIBUTION.

ALLOWED SPRAYED ITEMS TO OUTGAS TOLUENE OVERNIGHT

WEDNESDAY 11 MAY 1977

ADV. LCG TEST ELEMENT (PARALLEL FLOW)

ASSEMBLED FILM, WIRE MESH, AND TUBING



VACUUM BAGGED AND THERMAL CURED ADHESIVE AT 250 °F FOR 45 MIN.

ALLOWED TUBING TO PROTRUDE FROM VACUUM BAG TO REDUCE TUBE COLLASPING. TUBING COLLASPED PARTIALLY OUTSIDE OF THE WIRE MESH COVERAGE.

HYPOTHESIS: THE TUBING IS HEATED BY THE ALUMINUM BACKING PLATE AND SUBSEQUENTLY COLLASPES UNDER VACUUM CONDITIONS.

THE ALUMINUM PLATE WAS ADDED TO CREATE A FLAT SIDE ON THE TEST ELEMENT. THE FLAT SIDE SHOULD IMPROVE ELEMENT CONTACT WITH THE CONVEX ALUMINUM PLATE DURING THE TEST.

WEDNESDAY 18 MAY 1977

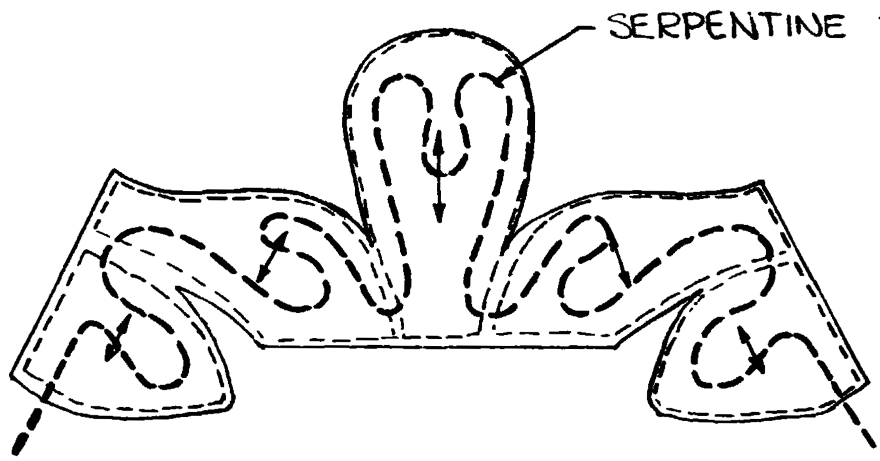
HEAD COOLER NO. 5

USED HAND-HELD "SEALINE" HEAT SEALER TO MAKE SEAMS.

SEAMS ARE STRONG BUT BURN-THROUGH OCCURRED IN SEVERAL PLACES.

WEDNESDAY 8 JUNE 1977

PREPARATIONS FOR NO. 6 & 7 HEAD COOLER FLAT PATTERN.



SILVER METAL MESH LAY-UP

FLAT PATTERNS NO. 6 & 7 WILL BE SEWN TOGETHER BY AL TAILOR.

SERPENTINE TUBE WAS THERMOFORMED AT 250°F FOR 2 HOURS. CLEANED WITH TOLUENE

ATTACH 1.5 MIL TF410 FILM TO CARDBOARD SIZING PATTERN. DEGREASE FILM WITH TOLUENE.

CUT 3 AG 5-2/0 METAL MESH SWATCHES. DEGREASE MESH BY SPRAYING SWATCHES WITH TOLUENE.

THURSDAY 9 JUNE 1977

HEAD COOLER NO. 6 & 7

MIX NORDBAK 50-93 ADHESIVE

10 ML RESIN
10 ML HARDENER
15 ML DILUENT (TOLUENE)

SPRAYED ADHESIVE ON FILM AND DAUBED THE ADHESIVE WITH A KIMWIPE TO IMPROVE DISTRIBUTION.

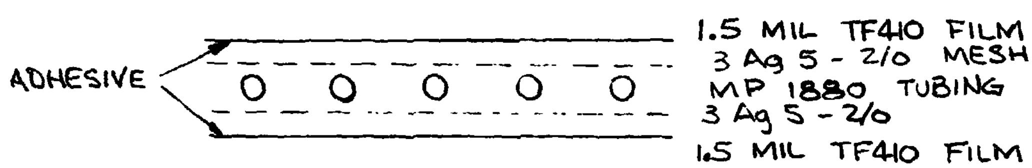
NO ADHESIVE APPLIED TO METAL MESH SWATCHES.

ADHESIVE APPLIED TO FILM WAS ALLOWED TO OUTGAS OVERNIGHT.

FRIDAY 10 JUNE 1977

HEAD COOLER NO. 6 & 7

ASSEMBLED LAYUP AS DESCRIBE



VACUUM BAGGED IN MYLAR.

ACCELERATED CURE FOR ADHESIVE USED.
(250 °F FOR 45 MIN.)

RESULTS:

GOOD ELASTICITY IN SWD. MINIMAL ELASTICITY IN LWD.

GOOD ADHESION AND PEEL STRENGTH.

SEAMS WILL BE MADE BY SEWING. COMF RT LINER INTEGRATED IN GARMENT DURING SEWING OPERATION.

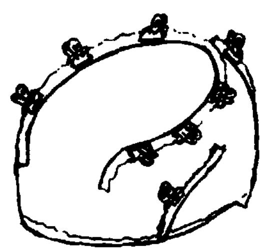
FRIDAY 17 JUNE 1977

COMFORT LINER FOR HEAD COOLER NO. 6

SEWING DONE AT:
A-1 TRIM & UPHOLSTERY

LINER MAT'L IS 100% COTTON T-SHIRT (BLUE).

TECHNIQUE -



SEAMS STITCHED WITH EXTERIOR SIDES FACING. AFTER SEWING LINER IS REVERSED.

SPRING CLIPS HOLD SEAMS TOGETHER FOR SEWING

ALL THREE COMPONENTS (INNER LINER, FLAT PATTERN & OUTER LINER) STITCHED BY MATCHED-EDGE LAPPING THEN REVERS D

SATURDAY 18 JUNE 1977

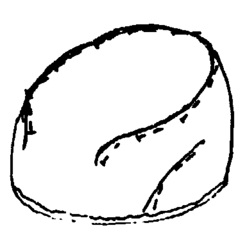
COMFORT LINER FOR HEAD COOLER NO. 5

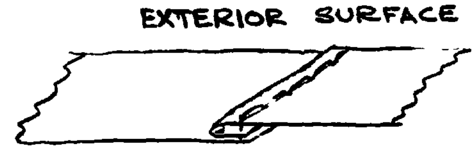
SEWING DONE AT:
HOME

LINER MAT'L IS "STRETCH & SEW" SYNTHETIC MATERIAL. "LYCRA"

HEAD COOLER #5 FLAT PATTERN HAS SEAMS MADE BY HEAT SEALING

TECHNIQUE -





STRAIGHT PINS HOLD SEAMS TOGETHER FOR SEWING

SEAMS STITCHED WITH ONE EDGE FOLDED INTO THE SEAM.

TUESDAY 21 JUNE 1977

FABRICATE HEAD COOLER FLAT PATTERNS NUMBERS 8 & 9

CUT 1.5 MIL TF410 POLYURETHANE FILM FROM SUPPLY ROLL AND TAPED FILM OVER CARDBOARD PATTERN. CLEANED FILM WITH TOLUENE AND LET SET TO OUTGAS FOR 6 HRS.

THERMOFORMED SERPENTINE TUBE FOR BOTH HEAD COOLERS.

CUT 3 Ag. 5 - 2/0 WIRE MESH FOR TWO LAYERS OF MESH IN EACH COOLER.

MIXED NORDBAK 50-93 ADHESIVE

10 ML RESIN
10 ML HARDENER
15 ML DILUENT (TOLUENE)

SPRAYED 4 PIECES OF FILM WITH ADHESIVE. DAUBED ADHESIVE WITH KIMWIPE TO IMPROVE DISTRIBUTION.

LET ADHESIVE OUTGAS OVERNIGHT.

WEDNESDAY 22 JUNE 1977

FABRICATE HEAD COOLER FLAT PATTERNS
NOS. 8 & 9

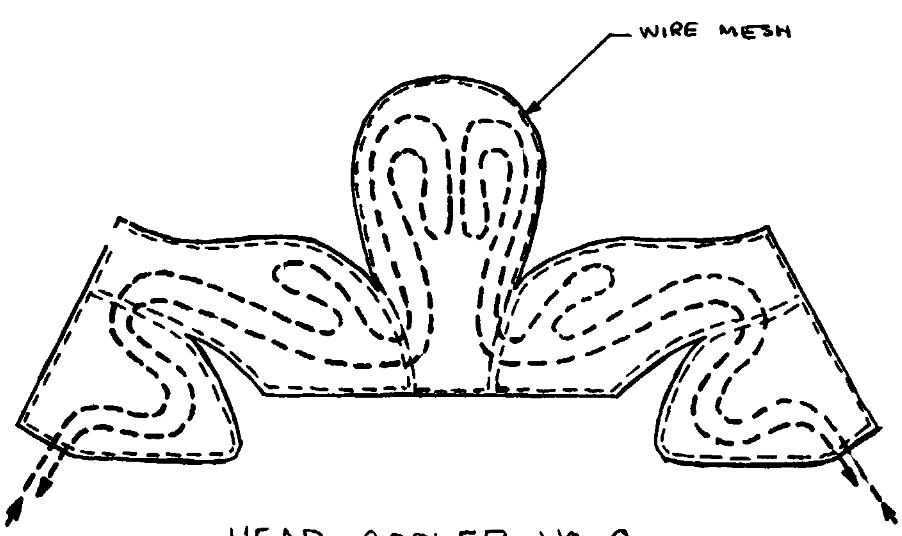
USED ACCELERATED THERMAL CURE OF
250 °F FOR 45-60 MIN. FOR ADHESIVE.

RESULTS:

GOOD ELASTICITY (SWD)
GOOD PEEL STRENGTH

HEAD COOLER NO. 8 SERPENTINE TUBE SAME AS PREVIOUS FOUR GARMENTS. SEE NOTES DATED 8 JUNE 1977.

HEAD COOLER NO. 9 HAS APPROXIMATELY TWO TIMES MORE TUBING THAN HEAD COOLER NO. 8. (SEE DIAGRAM BELOW)



HEAD COOLER NO. 9
TUBE PATTERN

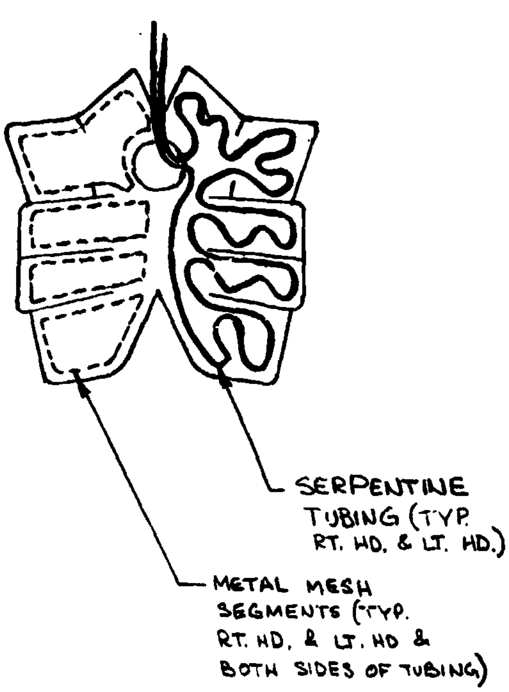
MONDAY 24 OCTOBER 1977

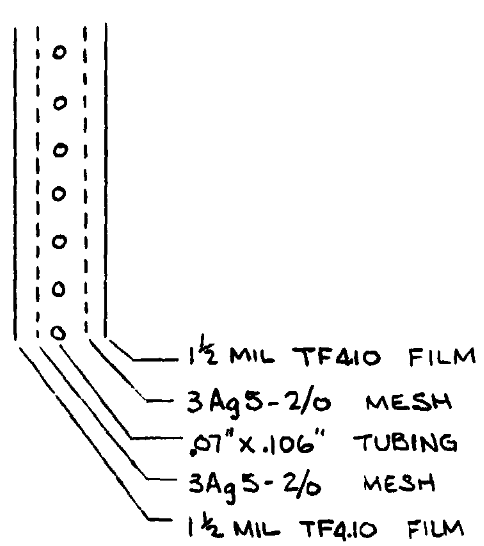
FABRICATE TEMPERATURE-CONTROL GARMENTS FROM PATTERNS RECEIVED FROM NASA-AMES

THERMOFORM TUBING -
USE .07" ID. x .106" OD. POLYURETHANE TUBING
TAPE TUBING LENGTH (~12 FEET) TO AN ALUMINUM SHEET IN SERPENTINE PATH FOR THERMOFORMING
THERMOFORM AT 250°F FOR 60 MIN.

TAPED 1½ MIL TF410 POLYURETHANE FILM OVER CARDBOARD PATTERNS FOR ADHESIVE APPLICATION AND GARMENT LAYUP

CUT 3Ag5-2/0 FLATTENED METAL MESH SEGMENTS FOR NEONATAL GARMENT.





MONDAY 24 OCTOBER 1977 (CONT'D)

MIXED NORDBAK 50-93 ADHESIVE

20 ML RESIN
20 ML HARDENER
20 ML DILUENT (TOLUENE)

SPRAYED FILM TAPED OVER CARDBOARD PATTERNS
DAUBED ADHESIVE WITH KIMWIPE TO IMPROVED
DISTRIBUTION

ALLOWED SPRAYED COMPONENTS TO OUTGAS OVERNIGHT

TUESDAY 25 OCTOBER 1977

ASSEMBLED NEONATAL GARMENT COMPONENTS AND VACUUM BAGGED.

USED ACCELERATED THERMAL CURE FOR ADHESIVE 250 °F FOR 90 MIN.

CUT 3Ag5-2/0 METAL MESH SEGMENTS FOR ZEONATAL GARMENT

REMOVED NEONATAL GARMENT FROM AUTOCLAVE. BAGGING MATERIAL STUCK TO ONE SIDE OF GARMENT

ASSEMBLED ZEONATAL GARMENT COMPONENTS AND VACUUM BAGGED. USED BLEED CLOTH ON BOTH SIDES OF GARMENT.

USED ACCELERATED THERMAL CURE ON ZEONATAL GARMENT. (250 °F FOR 90 MIN.)

REMOVED ZEONATAL GARMENT FROM AUTOCLAVE. NO STICKING PROBLEM.

BEGAN CLEANING NEONATAL GARMENT. STICKING OF VACUUM BAG MATERIAL AND SUBSEQUENT REMOVAL CAUSED THE GARMENT FILM TO SEPARATE IN SOME AREAS. PARTICULAR PROBLEM WAS OBSERVED AT TUBE/FILM FILET. THE PRIMARY DAMAGED AREA IS ONE SHOULDER/ARM. THE METAL MESH IS INTACT AND THE THERMAL DEGRADATION SHOULD BE MINIMAL.

APPENDIX B

PRODUCTION COST ANALSIS

ESTIMATE OF PRODUCTION COSTS/UNIT

HEAD COOLER

FABRICATION STEPS:	HRS
1. CUT POLYURETHANE FILM FROM SUPPLY ROLL	.5
2. TAPE FILM OVER CARDBOARD PATTERN (2)	.5
3. CLEAN FILM WITH TOLUENE	.25
(LET DRY FOR 4 HRS MINIMUM)	
4. THERMOFORM SERPENTINE TUBING	
a. TAPE TUBING TO PLATE IN SHAPE DESIRED	.5
b. AUTOCLAVE FOR 90 MIN. AT 250°F	–
c. REMOVE TUBING AND CLEAN WITH TOLUENE	.5
d. CLEAN PLATE WITH TOLUENE	.25
5. CUT METAL MESH TO PROPER SIZE AND CLEAN	1.5
6. MIX ADHESIVE. DILUTE WITH TOLUENE	.25
7. SPRAY ADHESIVE ON FILM AND DAUB	.5
(ALLOW 12HRS FOR ADHESIVE TO OUTGAS)	
8. PREPARE VACUUM BAG (USE MYLAR)	.25
9. LAYUP FLAT PATTERN IN VACUUM BAG	.5
10. THERMAL CURE FLAT PATTERN (60 MIN. AT 250°F)	–
11. REMOVE FLAT PATTERN FROM VACUUM BAG	.5
12. CUT OUT COMFORT LINERS	.25
	6.25 *

13. STITCH FLAT PATTERN AND COMFORT LINERS
14. SEW COMFORT LINERS AND FLAT PATTERN TOGETHER

} $50.00

* TIME TO FAB. ONE HEAD COOLER

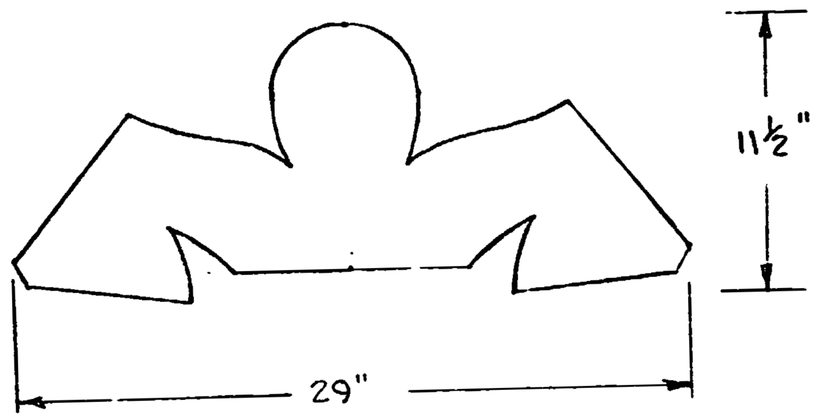
ESTIMATE OF MATERIAL COSTS

HEAD COOLER (6 UNITS TOTAL)

MATERIAL REQUIRED	COST
1. TF410 POLYURETHANE FILM (1½ MIL.) (6 SQ. YD.)	$ 15
2. 3 Ag 5-2/0 FLATTENED METAL MESH (36 SQ. FT.)	240
3. MP-1880 POLYURETHANE TUBING (72 FT.)	18
4. NORDBAK 50-93 ADHESIVE (½ GAL. RESIN, ½ GAL. HARDENER)	45
5. COMFORT LINER (LYCRA MATERIAL) (6 SQ. YD.)	60
6. JET-PAK SPRAY KIT	4
7. PLASTIC BARBED TUBING NIPPLES	12
	$ 394

PRODUCTION COST ANALYSIS

HEAD COOLER PATTERN



ORIGINAL PAGE IS
OF POOR QUALITY

ESTIMATE OF PRODUCTION COSTS/UNIT

HEAD/VEST COOLER

FABRICATION STEPS:	HRS
1. CUT POLYURETHANE FILM FROM SUPPLY ROLL	.5
2. TAPE FILM OVER CARDBOARD PATTERNS (4)	1.0
3. CLEAN FILM WITH TOLUENE	.5
(LET DRY FOR 4 HRS. MINIMUM)	
4. THERMOFORM SERPENTINE TUBING	
a. TAPE TUBING TO PLATE IN SHAPE DESIRED	1.0
b. AUTOCLAVE FOR 90 MIN. AT 250°F	
c. REMOVE TUBING AND CLEAN WITH TOLUENE	1.0
d. CLEAN PLATE WITH TOLUENE	.5
5. CUT METAL MESH TO PROPER SIZE AND CLEAN	2.0
6. MIX ADHESIVE. DILUTE WITH TOLUENE	.25
7. SPRAY ADHESIVE ON FILM AND DAUB	1.0
(ALLOW 12 HRS MIN. FOR ADHESIVE TO OUTGAS)	
8. PREPARE VACUUM BAGS (USE MYLAR)	.5
9. LAYUP FLAT PATTERNS IN VACUUM BAGS	1.0
10. THERMAL CURE FLAT PATTERNS FOR 60 MIN. AT 250°F	–
11. REMOVE FLAT PATTERNS FROM VACUUM BAGS	.5
12. CUT OUT COMFORT LINERS	.5
13. CONNECT TUBING MANIFOLD	.25
	10.5 *

$$\left.\begin{array}{l}\text{14. STITCH FLAT PATTERN AND COMFORT LINERS}\\ \text{15. SEW COMFORT LINERS AND FLAT PATTERN}\\ \quad\text{TOGETHER}\\ \text{16. ATTACH VELCRO FASTENERS (SEW)}\end{array}\right\}\ \$100.00$$

* TIME TO FAB. ONE HEAD/VEST COOLER

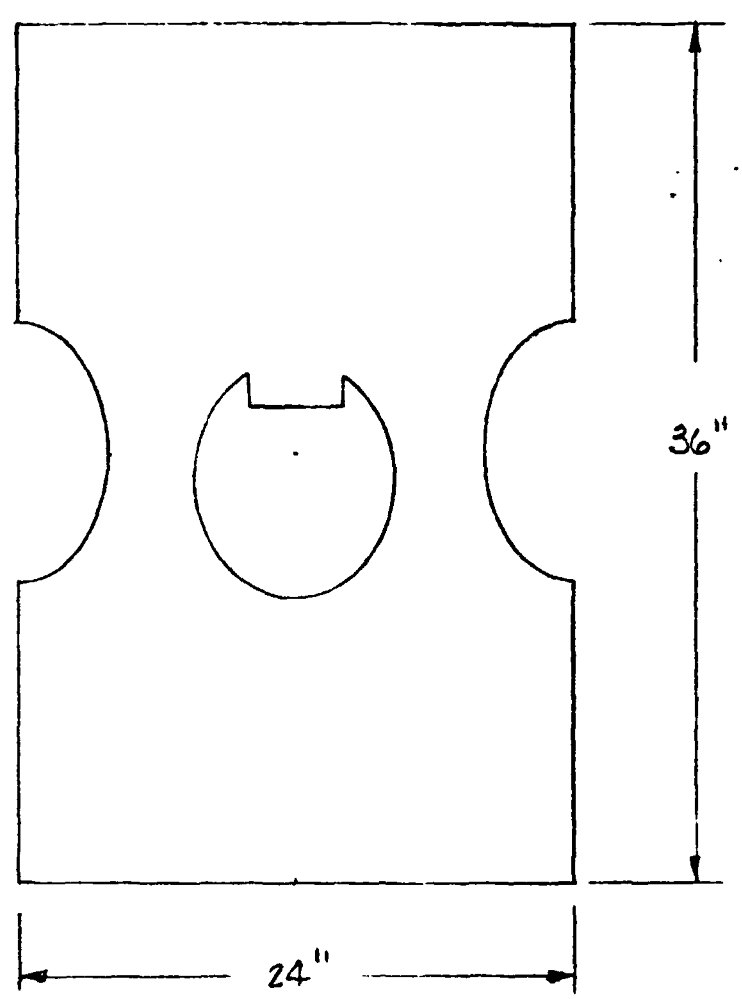
ESTIMATE OF MATERIAL COSTS

HEAD/VEST COOLER (6 UNITS TOTAL)

MATERIAL REQUIRED	COST
1. TF410 POLYURETHANE FILM (1½ MIL.) (15 SQ. YD.)	$ 38
2. 3 Ag 5 - 2/0 FLATTENED METAL MESH (120 SQ. FT.)	555
3. MP-1880 POLYURETHANE TUBING (432 FT.)	108
4. NORDBAK 50-93 ADHESIVE (½ GAL. RESIN, ½ GAL. HARDENER)	45
5. COMFORT LINER (LYCRA MATERIAL) (15 SQ. YD.)	150
6. JET-PAK SPRAY KIT	4
7. PLASTIC BARBED TUBING NIPPLES	12
	$ 912

PRODUCTION COST ANALYSIS

VEST COOLER PATTERN



ESTIMATE OF PRODUCTION COSTS/UNIT

FULL BODY / HEAD COOLER

FABRICATION STEPS:	HRS
1. CUT POLYURETHANE FILM FROM SUPPLY ROLL	.5
2. TAPE FILM OVER CARDBOARD PATTERNS (6)	1.5
3. CLEAN FILM WITH TOLUENE (LET DRY FOR 4 HRS. MINIMUM)	1.0
4. THERMOFORM SERPENTINE TUBING	
a. TAPE TUBING TO PLATE IN SHAPE DESIRED	2.0
b. AUTOCLAVE FOR 90 MIN. AT 250 °F	—
c. REMOVE TUBING AND CLEAN WITH TOLUENE	2.0
d. CLEAN PLATE WITH TOLUENE	1.0
5. CUT METAL MESH TO PROPER SIZE AND CLEAN	4.0
6. MIX ADHESIVE. DILUTE WITH TOLUENE	.5
7. SPRAY ADHESIVE OF FILM AND DAUB (ALLOW 12 HRS FOR ADHESIVE TO OUTGAS)	2.0
8. PREPARE VACUUM BAG (USE MYLAR)	.8
9. LAYUP FLAT PATTERNS IN VACUUM BAGS	1.5
10. THERMAL CURE FLAT PATTERN (60 MIN. AT 250°F)	-
11. REMOVE FLAT PATTERN FROM VACUUM BAG	1.0
12. CUT OUT COMFORT LINERS	1.0
13. CONNECT TUBING MANIFOLD	.5
	19.3 *

14. STITCH FLAT PATTERN AND COMFORT LINERS 15. SEW COMFORT LINERS AND FLAT PATTERN TOGETHER 16. ATTACH VELCRO FASTENERS (SEW)	$150.00

* TIME TO FAB. ONE FULL BODY/HEAD COOLER

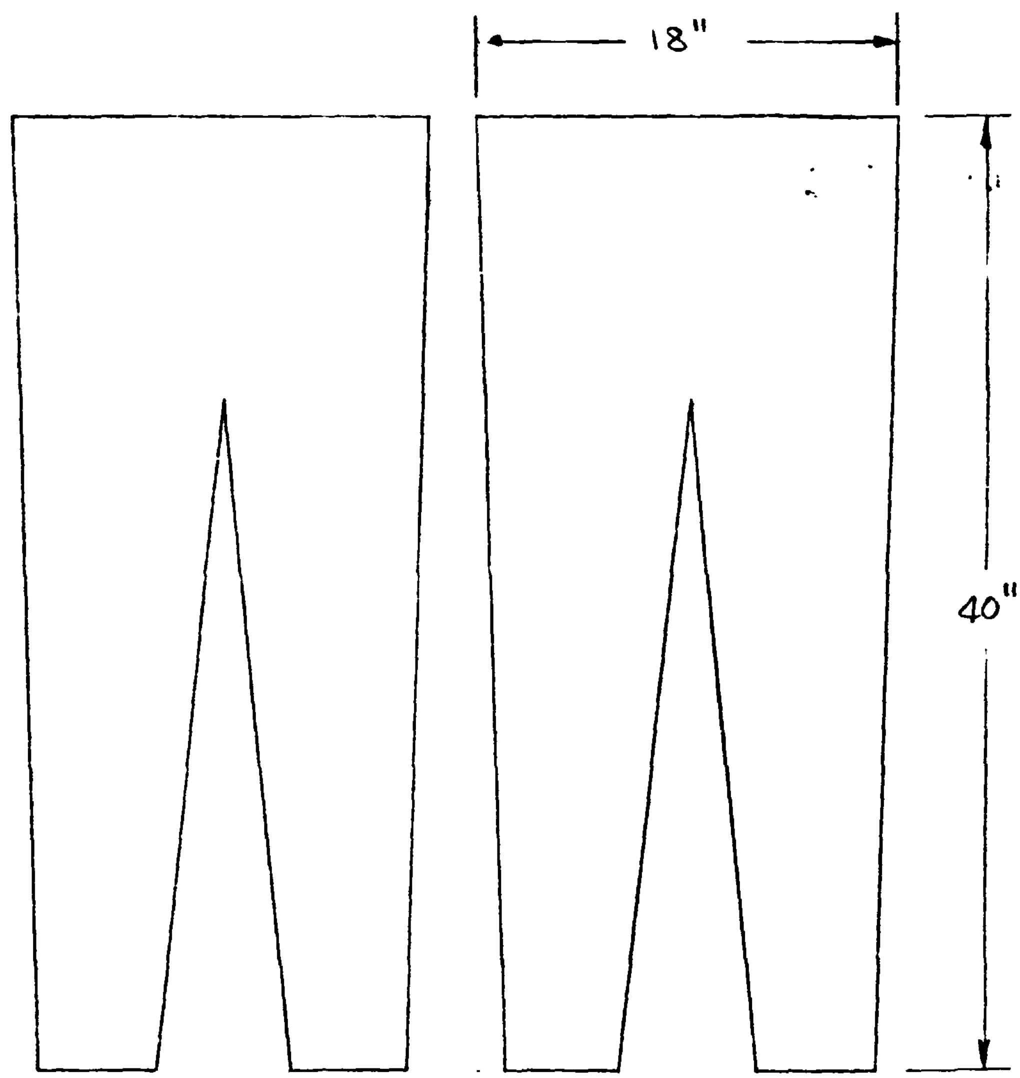
ESTIMATE OF MATERIAL COSTS

FULL BODY / HEAD COOLER (6 UNITS TOTAL)

MATERIAL REQUIRED	COST
1. TF410 POLYURETHANE FILM (1½ MIL.) (30 SQ. YD.)	$ 75
2. 3 Ag 5-2/0 FLATTENED METAL MESH (252 SQ. FT.)	1083
3. MP1880 POLYURETHANE TUBING (1152 FT.)	288
4. NORDBAK 50-93 ADHESIVE (½ GAL. RESIN, ½ GAL. HARDENER)	45
5. COMFORT LINER (LYCRA MATERIAL) (30 SQ. YD.)	300
6. JET-PAK SPRAY KIT	4
7. PLASTIC BARBED TUBING NIPPLES	48
	$ 1843

PRODUCTION COST ANALYSIS

LOWER BODY COOLER PATTERN



APPENDIX C

THERMAL COMPARISON TEST

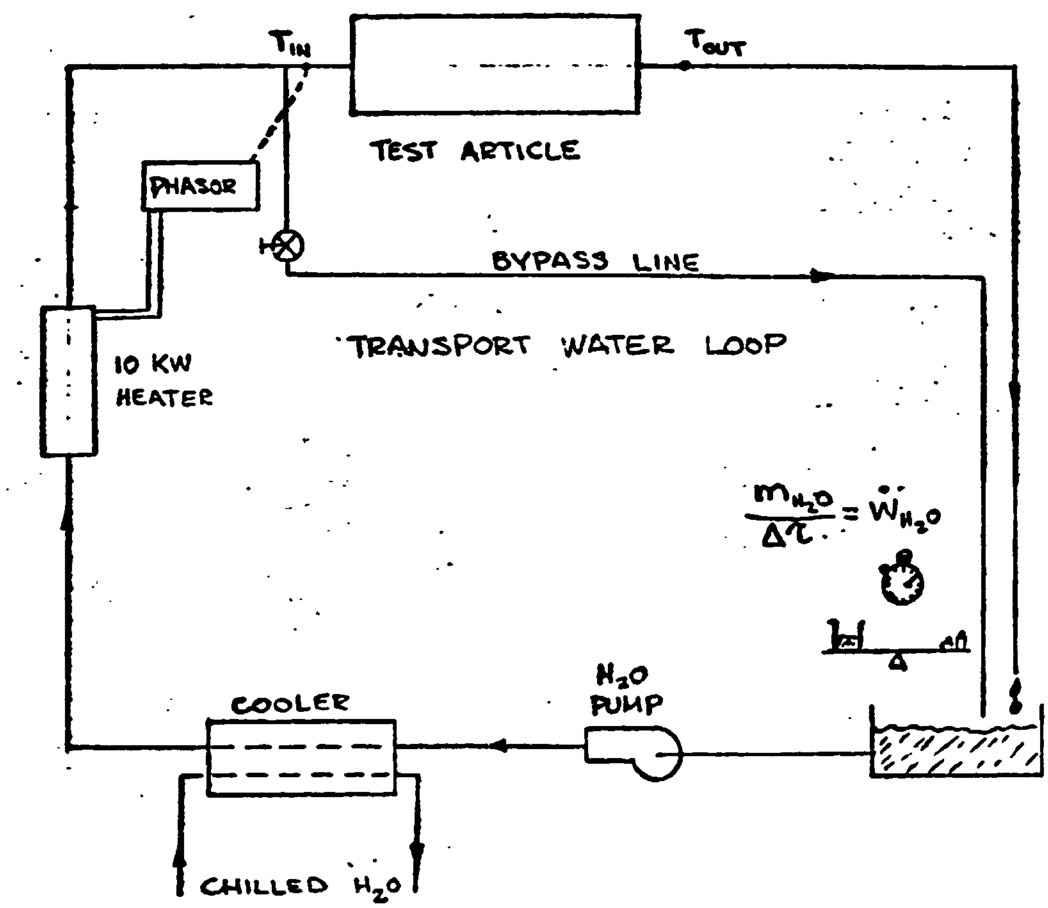


FIGURE 1 FLOW SCHEMATIC

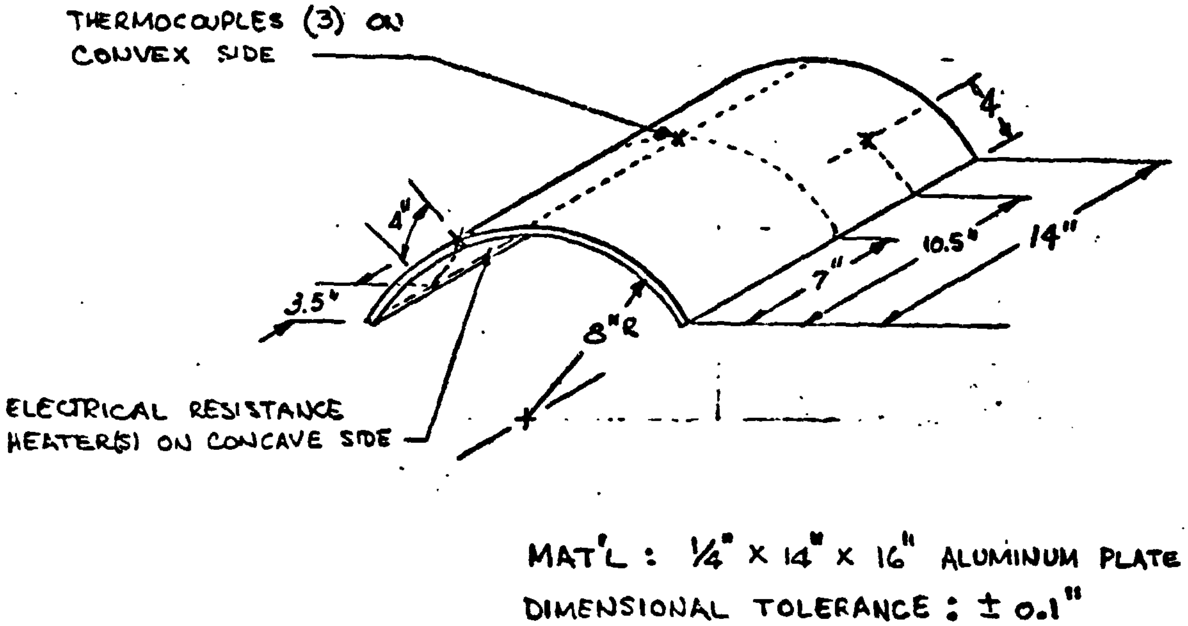


FIGURE 2 - PLATE CONSTRUCTION & INSTRUMENTATION

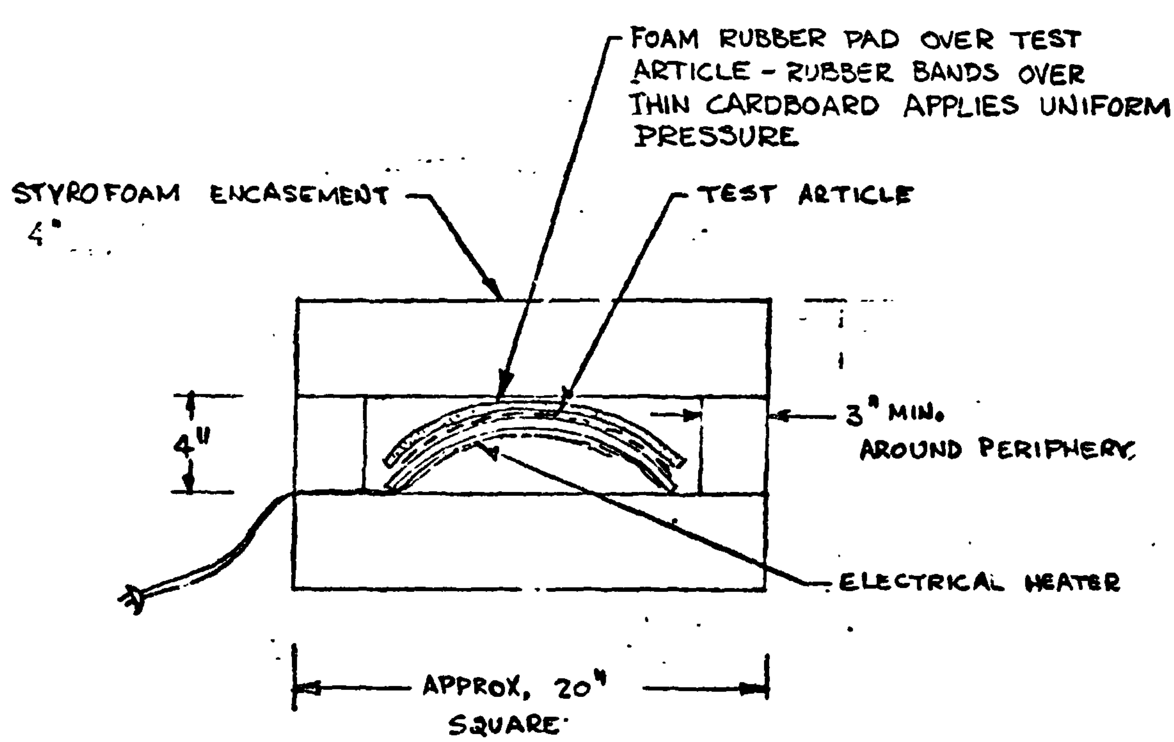


FIGURE 3 - TEST ARTICLE INSULATION REQUIREMENT

TEST ARTICLE DESCRIPTION

FLEXITHERM:

HEAT TRANSFER AREA = 75.75 $in.^2$
FLOW PASSAGE SPACING ≅ 0.10 in.

SHUTTLE "REPRESENTATIVE":

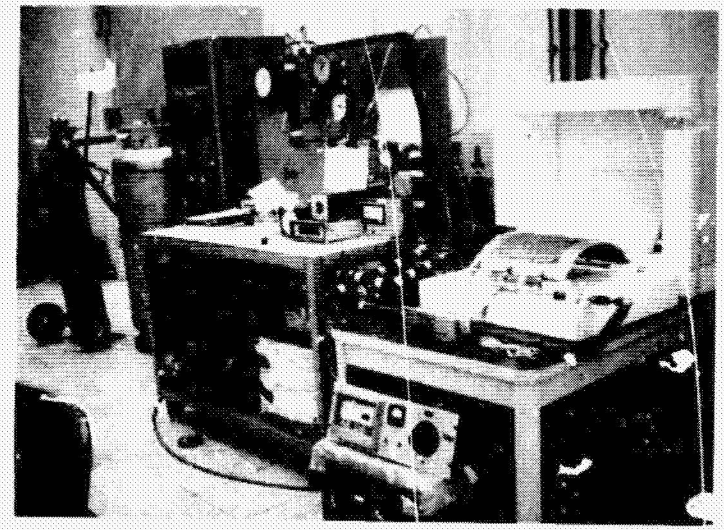
HEAT TRANSFER AREA = 109.69 $in.^2$
TUBING SIZE – 1/16" I.D. x 1/8" O.D x 18" LONG

TUBE SPACING = 5/16"
NUMBER OF TUBES = 36
MANIFOLD TUBE SIZE = 1/2"-.049" WALL

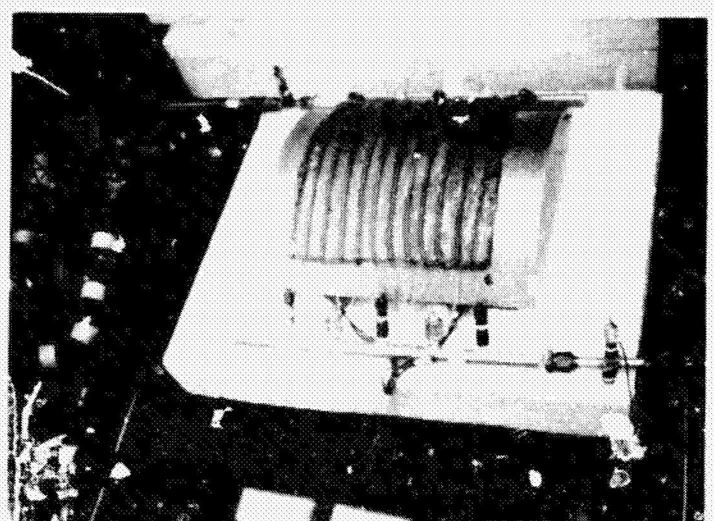
TUBE/FIN:

HEAT TRANSFER AREA = 105.70 $in.^2$
TUBING SIZE – .070" I.D. x .106" O.D. x 18" LONG

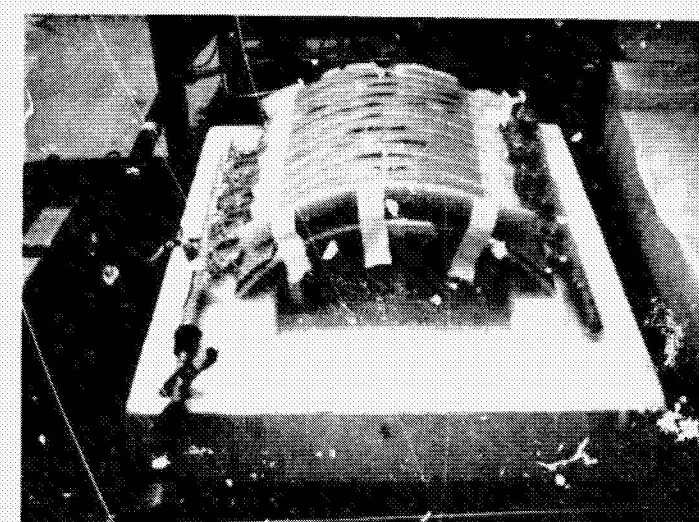
TUBE SPACING = 0.89 in.
NUMBER OF TUBES = 11
MANIFOLD TUBE SIZE = 1/2" O.D. – .049" WALL



TEST SET-UP



TUBE . LM LCG



REPRESENTATIVE SHUTTLE LCG
(RUBBER BAND HOLD DOWN)

TUBE/FILM LCG TEST DATA

TUBE/FIN LCG

TEST POINT	DATE	T_{AMB} °F	SYS. PRESS.	TIME START	TIME STOP	Δ MIN.	HEATER POWER AMPS	HEATER POWER VOLTS	TIME MIN.	TIME/Δ	BTU'S/HR	WATER T_{OUT}	WATER T_{IN}	ΔT °F	$\dot{W}$ PPH	$\dot{Q}$ B/HR
1	5/27/77	90°F	4 PSIG	10:19	10:14	5 MIN.	3.62	52.50	1.1833 MIN	.2367	153.55	72.8	57°F	15.5	8.94 W	138.57
2				10:39	10:44	5	3.64	52.60	1.50	.30	196.04	62.2	57.7	4.5	89.57	177.84
3				10:49	10:54	5	3.62	52.50	1.1833	.2367	153.55	65.1	58	7.1	20.75	147.33
4				11:02	11:12	10	3.65	52.60	2.5833	.2583	169.25	68.2	61.2	7.0	20.75	145.25
5				11:26	11:38	5	3.65	52.60	1.20	.24	157.26	75.7	63.1	12.6	8.72	109.87
6				12:46	12:51	5	3.65	52.30	1.50	.30	195.46	65.1	61.1	4.0	38.33	153.32
7				12:59	1:05	6	3.65	[illegible]	1.0833	.1806	117.67	76.6	65.4	11.2	8.94	100.13
8				1:22	1:32	10	3.62	[illegible]	1.75	.175	113.30	70.9	65.7	5.2	20.42	106.18
9				1:43	1:53	5	3.64	[illegible]	0.4667	.0933	60.74	79.3	72.0	7.3	8.94	65.26
10		95°F	5-10	2:35	2:40	5	3.64	[illegible]	1.2833	.2567	167.11	75.5	59.0	16.5	8.94	147.51
11				2:45	2:50	5	3.63	[illegible]	1.6667	.3333	216.58	68.7	59.	9.3	20.78	194.18
12				3:00	3:05	5	3.63	52.40	1.6333	.3267	212.49	65.6	61	4.6	39.77	182.99
13				3:16	3:21	5	3.63	52.40	1.0167	.2033	131.98	77.2	64.5	12.7	8.14	111.99
14				3:25	3:30	5	3.63	52.40	1.20	.24	155.81	72.0	65.0	7.0	20.75	145.25
15				3:41	3:46	5	3.63	52.40	[illegible]	.22	142.82	80.4	70.1	10.3	9.87	101.66
16	6/30/77	95°F	3.5	9:34	9:39	5	3.63	52.57	1.25	.25	165.07	76.2	58.5	17.7	8.70	157.53
17				9:43	9:48	5	[illegible]	52.57	1.3833	.2767	182.70	68	58.5	9.5	20.42	193.97
18				9:51	9:56	5	3.68	52.57	1.95	.39	257.51	63.9	58.3	5.6	39.12	219.07
19				10:11	10:16	5	3.14	52.70	1.3833	.2767	181.16	68.7	60.	8.7	20.42	177.65
20				10:24	10:34	10	3.64	52.70	1.80	.18	117.83	75.7	70.6	5.1	20.28	103.12
		●	●	●	●		●	●	●			●	●		●	

$\phi = \Gamma_c$

● RECORDED DATA

REPRESENTATIVE SHUTTLE LCG TEST DATA

REPRESENTATIVE SHUTTLE LCG

TEST POINT	DATE	T AMB	SYS. PRESS.	TIME START	TIME STOP	Δ MIN.	HEATER POWER AMPS	VOLTS	TIME MIN.	TIME/Δ	BTU'S/HR	WATER T_{OUT}	T_{IN}	ΔT °F	W PPH	Q B/HR
1	5/25/77	95°F	29	9:37	9:52	15	3.64	52.69	6.1167	.4078	266.94	66	55	11	20	220
2				10:08	10:18	10	3.64	52.66	3.50	.350	228.97	70	60	10	20	200
3				10:31	10:41	10	3.64	52.69	3.05	.305	199.46	74	65	9	20	180
4				10:56	11:06	10	3.65	52.70	2.5833	.2583	169.58	78	70	8	20	160
5				11:13	11:23	10	3.65	52.75	2.05	.205	134.71	81	75	6	20	120
6				12:51	1:01	10	3.68	53.32	4.40	.44	294.66	62	55	7	40	280
7				1:07	1:17	10	3.67	53.26	3.8667	.3867	257.98	66	60	6	40	240
8				1:27	1:37	10	3.68	53.11	3.25	.325	216.79	70	65	5	40	200
9				1:43	1:53	10	3.67	52.20	2.8167	.2817	184.19	74	70	4	40	160
10				2:18	2:28	10	3.65	53.2	3.95	.395	263.93	64	60	4	60	240
11	5/26/77	90°F	21	12:48	12:58	10	3.63	52.37	3.5833	.3583	219.50	67	58	9	20	180
12				12:59	1:09	10	3.63	52.58	3.4833	.3483	226.03	64	58	6	40	240
13				1:12	1:22	10	3.63	52.30	3.75	.375	247.18	62	58	4	60	240
14				1:36	1:46	10	3.63	52.30	2.6167	.2617	167.57	68	65	3	60	180
15				1:48	1:58	10	3.63	52.30	2.4833	.2483	160.89	70	66	4	40	160
16				2:02	2:12	10	3.65	52.40	2.50	.250	163.19	72	65	7	20	140
17				2:23	2:33	10	3.65	52.40	2.0333	.2033	132.71	74	70	4	40	160
18				4:02	4:12	10	3.72	53.50	1.95	.195	132.45	76	70	6	20	120
19	6/1/77	90°F	30	1:00	1:08	8	3.65	52.60	2.3333	.2917	191.14	75.5	57.8	17.7	8.63	152.75
20				1:18	1:26	8	3.65	52.60	2.8667	.3583	234.78	65.9	54.4	11.5	18.10	217.55
21				1:30	1:38	8	3.65	52.60	2.0333	.2542	166.57	72.6	54.9	17.6	8.55	150.48
22	6/6/77	90°F	30	10:33	10:38	5	3.61	52.09	1.1833	.2367	151.91	77	59.9	17.1	8.50	145.35
23				10:48	10:53	5	3.60	52.02	1.0833	.2167	138.51	79.8	64.8	15.	8.59	128.85
24				10:59	11:04	5	3.61	52.02	.9833	.1967	126.07	82.8	70.1	12.7	8.55	108.09
25		95°F	29	9:29	9:34	5	3.59	52.20	1.4167	.2833	181.20	76.4	54.8	21.6	8.55	184.68
26				9:44	9:50	6	3.59	52.15	1.7167	.2861	182.81	81.6	59.7	21.9	8.50	186.15
27				9:57	10:03	6	3.60	52.15	1.70	.2831	181.40	84.	65.	19.0	8.15	154.97
28				10:11	10:16	5	3.59	52.15	1.4333	.2867	180.89	87.2	69.6	17.6	8.41	148.02
		●	●	●	●		●	●	●			●	●		●	

Φ = T.

● RECORDED DATA

FLEXITHERM LCG TEST DATA

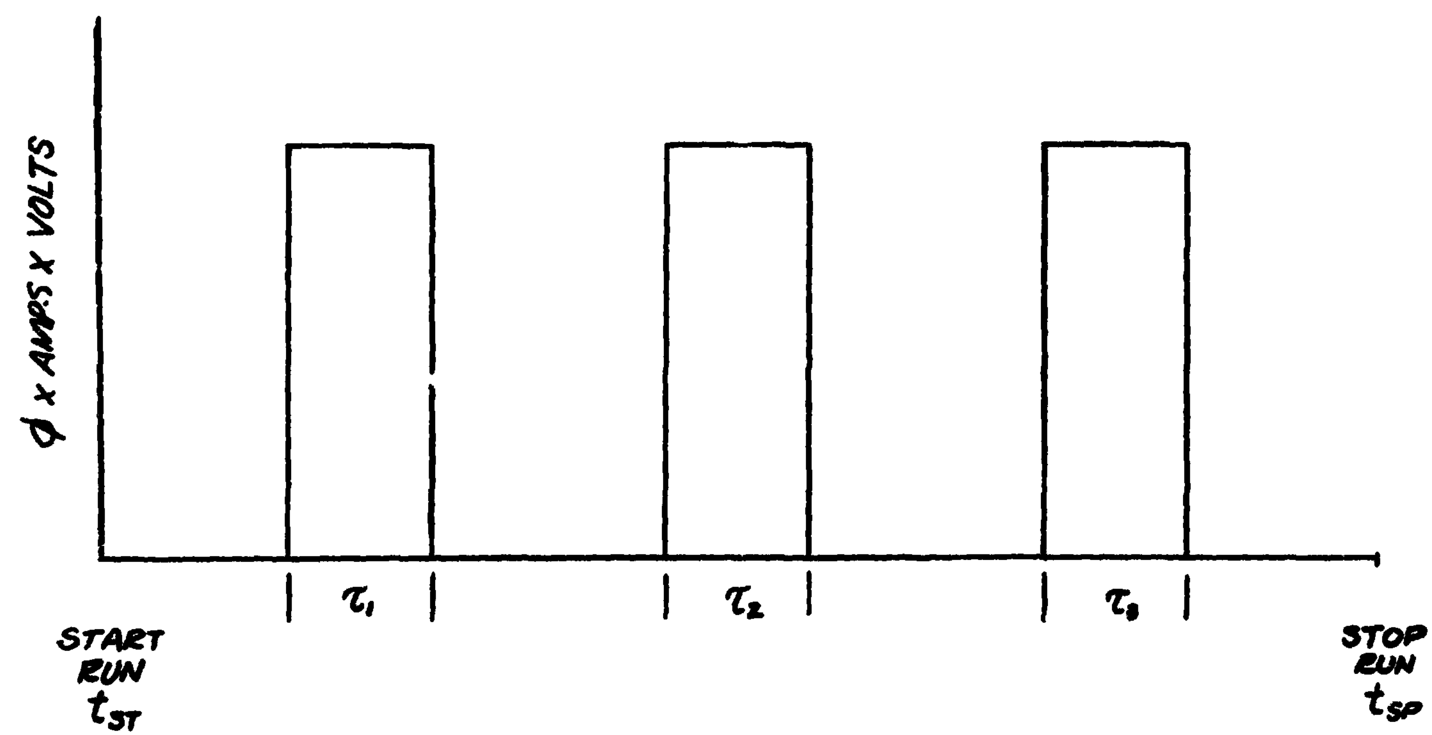
FLEXITHERM LCG

TEST POINT	DATE	$T_{SKIN,AVG}$	SYS PRESS.	TIME START	TIME STOP	TIME Δ MIN.	HEATER POWER AMPS	HEATER POWER VOLTS	HEATER POWER TIME MIN.	HEATER POWER TIME/Δ	HEATER POWER BTU'S/HR	WATER T_{OUT}	WATER T_{IN}	WATER ΔT °F	WATER $\dot{W}$ PPH	WATER $\dot{Q}$ B/HR
1	5/31/77	95°F	30 PSIG	10:21	10:26	5	3.64	52.50	1.65	.330	215.25	61.8	56.1	5.7	38.99	222.24
2				10:32	10:37	5	3.62	52.50	1.45	.29	188.11	64.1	55.6	8.5	20.55	174.68
3				10:59	11:04	5	3.65	52.60	1.2167	.2433	158.58	64.7	48.5	16.2	8.72	141.26
4				11:24	11:29	5	3.64	52.70	1.1833	.2367	154.97	70.5	56.4	14.1	8.7?	122.95
5				12:44	12:49	5	3.62	[illegible]	1.3833	.2767	179.75	69.7	62.	7.7	21.48	157.70
6				12:54	12:59	5	3.61	52.56	1.40	.28	181.32	66.9	61.8	5.1	39.12	199.51
7				1:04	1:09	5	3.65	52.46	0.6167	.1233	80.14	[illegible]	62.6	11.6	9.25	107.30
8				1:15	1:20	5	3.63	52.48	1.3667	.2733	177.70	70.3	62.7	7.6	20.29	154.20
9				1:25	1:31	6	3.61	52.48	2.0167	.3361	217.52	67.6	62.8	4.8	39.12	187.78
10				1:42	1:47	5	3.61	52.48	1.3333	.2667	172.45	69.3	64.8	4.5	39.12	[illegible]
11				1:52	1:58	6	3.64	52.52	1.1333	.1889	123.25	76.6	66.0	10.6	8.99	95.29
12	5/31/77	90°F	30	2:41	2:46	5	3.63	52.50	1.25	.25	162.61	66.1	53.6	12.5	8.65	107.88
13				2:53	2:58	5	3.66	52.56	1.35	.27	177.94	63.3	55.2	8.1	20.92	162.16
14				3:05	3:10	5	3.63	52.63	1.4167	.2833	184.72	60	55.2	4.8	38.99	127.15
15				3:21	3:28	7	3.63	52.60	1.1833	.2367	154.25	70.3	57.8	10.5	9.27	95.24
16				3:38	3:43	5	3.63	52.65	1.2167	.2433	158.55	66.8	60.2	6.6	20.02	132.15
17				3:56	4:01	5	3.67	52.95	0.56	.1120	74.28	73.8	65.3	8.5	9.21	78.29
18				4:12	4:17	5	3.68	52.94	0.56	.113	74.47	78	70.6	7.4	8.94	66.16
		●	●	●	●		●	●	●			●	●		●	

$\phi = L$

● RECORDED DATA

DETERMINATION OF HEATER POWER INPUT PER TEST POINT



$$\text{HEATER POWER} = \phi \times \text{AMPS} \times \text{VOLTS} \times \frac{\sum \tau_i}{t_{SP} - t_{ST}}$$